Quantitative Assessment of Knee Progression Angle During Gait in Children With Cerebral Palsy

Jon R. Davids, MD, Nina Q. Cung, BS, Robin Pomeroy, MS, Brooke Schultz, MS, Leslie Torburn, DPT, Vedant A. Kulkarni, MD, Sean Brown, MA, and Anita M. Bagley, PhD, MPH

Background: Abnormal hip rotation is a common deviation in children with cerebral palsy (CP). Clinicians typically assess hip rotation during gait by observing the direction that the patella points relative to the path of walking, which is referred to as the knee progression angle (KPA). Two kinematic methods for calculating the KPA are compared with each other. Video-based qualitative assessment of KPA is compared with the quantitative methods to determine reliability and validity.

Methods: The KPA was calculated by both direct and indirect methods for 32 typically developing (TD) children and a convenience cohort of 43 children with hemiplegic type CP. An additional convenience cohort of 26 children with hemiplegic type CP was selected for qualitative assessment of KPA, performed by 3 experienced clinicians, using 3 categories (internal, >10 degrees; neutral, -10 to 10 degrees; and external, >-10 degrees).

Results: Root mean square (RMS) analysis comparing the direct and indirect KPAs was 1.14+0.43 degrees for TD children, and 1.75+1.54 degrees for the affected side of children with CP. The difference in RMS among the 2 groups was statistically, but not clinically, significant ($P=0.019$). Intraclass correlation coefficient revealed excellent agreement between the direct and indirect methods of KPA for TD and CP children (0.996 and 0.992, respectively; $P<0.001$). For the qualitative assessment of KPA there was complete agreement among all examiners for 17 of 26 cases (65%). Direct KPA matched for 49 of 78 observations (63%) and indirect KPA matched for 52 of 78 observations (67%).

Conclusions: The RMS analysis of direct and indirect methods for KPA was statistically but not clinically significant, which supports the use of either method based upon availability. Video-based qualitative assessment of KPA showed moderate reliability and validity. The differences between observed and calculated KPA indicate the need for caution when relying on visual assessments for clinical interpretation, and demonstrate the value of adding KPA calculation to standard kinematic analysis.

Level of Evidence: Level II—diagnostic test.

Key Words: knee progression angle, gait, quantitative assessment, cerebral palsy

(*J Pediatr Orthop* 2018;38:e219–e224)

Observational gait analysis (OGA) includes direct visualization of gait deviations in the coronal and sagittal planes. Deviations in the transverse plane are inferred from deviations observed in the other planes. Abnormal hip rotation is a common deviation in children with neuromuscular disorders such as cerebral palsy (CP).[1–11] Children with CP, who have increased femoral anteversion on the clinical examination, and exhibit increased internal hip rotation during gait, are candidates for femoral derotation osteotomy.[2] In these children, surgical correction of the skeletal deformity (ie, the femoral anteversion) will result in resolution of the dynamic gait deviation (ie, the increased hip internal rotation).[4,5,7,11–13] Clinicians typically assess the direction and magnitude of hip rotation during gait by observing the direction that the patella points relative to the path of walking, which is referred to as the knee progression angle (KPA).[2,6,8,14] The KPA can be defined as the position of the knee flexion/extension axis relative to the gait line of progression. The observed KPA is influenced by both pelvic and hip rotation deviations in the transverse plane (Fig. 1).

Despite widespread use and utility of assessing KPA during OGA, relatively little has been done to determine the accuracy of observational techniques.[3,15–18] In addition, quantitative assessment of KPA is not part of the routine kinematic calculations of commercially available gait analysis software packages. In the current study we developed and compared 2 methods for calculating the KPA: the directly calculated method (direct KPA) from projection of the line defined by the knee joint center and lateral knee marker relative to a global reference frame; and the indirectly calculated method (indirect KPA), defined as the sum of ipsilateral pelvic and hip transverse plane kinematics. Calculation of the direct KPA required development of site-specific software, while calculation of

From the Shriners Hospitals for Children-Northern California, Sacramento, CA.

J.R.D.: study design, data measurements, manuscript preparation. N.Q.C.: statistical analysis, manuscript preparation. R.P.: data measurements, manuscript preparation. B.S.: study design, data measurement. L.T.: data measurements, manuscript preparation. V.A.K.: study design, data measurements, manuscript preparation. S.B.: validation work, manuscript preparation. A.M.B.: study design, validation work, statistical analysis, manuscript preparation.

None of the authors received financial support for this study.

The authors declare no conflicts of interest.

Reprints: Jon R. Davids, MD, Shriners Hospital for Children, 2425 Stockton Boulevard, Sacramento, CA 95817. E-mail: jdavids@shrinenet.org.

DOI: 10.1097/BPO.0000000000001134

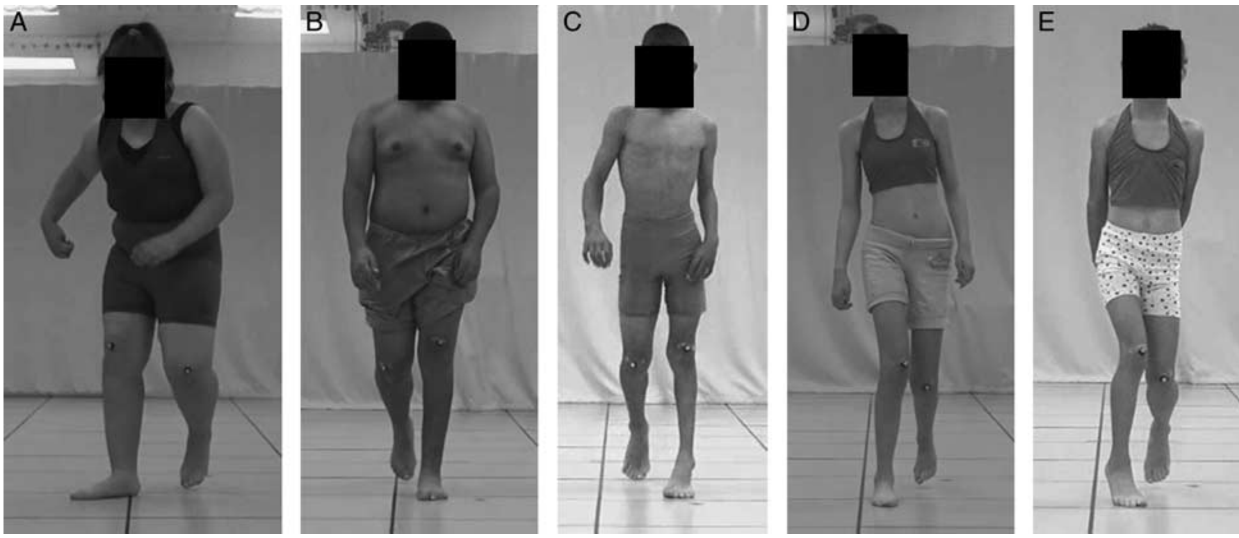

FIGURE 1. Clinical examples of a variety of knee progression angles (KPA) in children with cerebral palsy (CP). A, Thirteen-year-old female with right hemiplegic CP, showing an external KPA on the right side. Kinematic analysis revealed increased external rotation of the pelvis. B, Fifteen-year-old male with asymmetric diplegic CP, showing a neutral KPA on the left side. Kinematic analysis revealed normal pelvic and hip rotation. C, Eight-year-old male with left hemiplegic CP, showing a neutral KPA on the left side. Kinematic analysis revealed increased external rotation of the pelvis and internal rotation of the hip. These offsetting deviations resulted in a neutral KPA. D, Eleven-year-old female with right hemiplegic CP, showing an internal KPA. Kinematic analysis revealed increased internal pelvic rotation. E, Seven-year-old female with right hemiplegic CP, showing an internal KPA. Kinematic analysis revealed increased internal hip rotation.

the indirect KPA utilized data routinely collected with standard, commercially available kinematic software packages. In addition, quantitative calculation of KPA was transformed into qualitative categories and compared with clinicians' qualitative assessment of KPA via video-based OGA, to determine the accuracy of the common clinical technique. The goals of the current study were to (1) establish the accuracy of the more easily available indirect method relative to the presumably more precise direct method; and (2) determine the reliability and validity of commonly used observational, qualitative techniques (in daily clinical practice and when quantitative gait analysis is not available) relative to the computer-based quantitative techniques.

METHODS

The study design was a retrospective, cross-sectional, cohort study of a diagnostic test, with consistently applied reference standard and blinding, resulting in level II evidence. The study was reviewed and approved by our institution's research committee. The KPA was calculated by both the direct and indirect methods for the right side of 32 typically developing (TD) children (14 boys, 18 girls; mean age, 10.4 ± 3.1 y) and the affected side of a convenience cohort of 43 children with hemiplegic type CP, Gross Motor Function Classification System levels I and II (26 right sides, 17 left sides; 21 boys, 22 girls; mean age, 10.7 ± 3.2 y).[19] An additional convenience cohort of 26 children with hemiplegic type CP, Gross Motor Function Classification System levels I and II (15 right sides, 11 left sides; 15 boys, 11 girls; mean age, 10.6 ± 3.0 y) was selected for qualitative assessment of KPA, which was performed by 3 experienced clinicians (2 pediatric orthopaedic surgeons and 1 physical therapist). The qualitative assessments were made from different gait trials that were collected on the same day of testing as the gait trials used for quantitative calculation of KPA. The difference in the number of subjects utilized for distinct portions of the study was based upon convenience. A larger number of cases (n = 43) was used for the mathematical calculations of KPA by direct and indirect methods, reflecting the cases most readily available in our Motion Lab database and the availability of technician time for running the data through the appropriate software package. A smaller number of cases (n = 26) was used for clinician visual, qualitative assessment of KPA, in recognition of the limited time available to the clinicians for performing these assessments.

For the direct method, KPA (direct KPA) was calculated from the projection of a line determined by the lateral knee marker and the calculated knee joint center (midpoint of medial and lateral knee markers in the static pose) projected to the floor of the lab (xy). The position of that line relative to the lab x-axis (medial/lateral) was calculated. For validation purposes, a TD adult male walked in the motion lab with his "patella" in a variety of positions: internal, neutral, and external. The resulting data output from site-specific software matched this positioning, providing satisfactory validation. In addition, the subject walked diagonally in the lab instead of along the walkway, which is aligned with the lab global x-axis. As was predicted, both the pelvic rotation and the direct calculation of the knee progression angle were skewed. Although the subject walked in a neutral rotation manner, because those measures are calculated relative to the global lab, the measured rotation profiles were not neutral. It should be noted that we did not have a rigid biomechanical model to set positioning of the knee to precise degrees of rotation.

For the indirect method, KPA (indirect KPA) was generated from the sum of the ipsilateral pelvis and hip transverse plane rotations. For validation purposes, the summation algorithm and resulting indirect KPAs were double-checked for accuracy by a senior member of the research staff.

Root mean square (RMS) analysis for the direct and indirect KPA measures were calculated for the single support subphase of stance for each subject, providing the mean absolute differences between the 2 methods. Intraclass correlation coefficients (ICC) model 3,1 and 95% confidence intervals (95% CI) were calculated using SPSS statistical package version 24 (SPSS Inc., Chicago, IL) for the direct and indirect methods for all 43 children with hemiplegic type CP and 32 TD children. The ICC values were interpreted as follows: values <0.5 were poor, values between 0.5 and 0.75 moderate, values between 0.75 and 0.9 were good, and values >0.90 were excellent.[20] Statistical significance of the ICC estimates were determined by $P<0.05$.

Initially, 3 experienced clinicians attempted to visually assess 26 subjects with hemiplegic CP by viewing coronal plane walking videos and categorizing the KPA of the stance limb during the single support subphase of stance as extremely internal, internal, neutral, external, or extremely external, using the guidelines found in the Edinburgh Visual Gait Score (EVGS).[18] As the subjects in the videos did not have the proper peri-patellar skin marking as described by the EVGS, accurately grading the KPA in the 5 level scheme was not possible. By consensus of the clinicians, the assessments of KPA were made in a 3 level scale (internal, >10 degrees; neutral, between 10 degrees internal and 10 degrees external; and external, >10 degrees) for the subsequent analysis. Similarly, the direct and indirect KPA values were grouped categorically (external, >-10 degrees; neutral, -10 to 10 degrees; internal, >10 degrees) to facilitate comparison with the OGA scores of KPA. An intrarater reliability analysis was performed to assess the degree of agreement between KPA categories determined from the direct or indirect quantitative method and the KPA ratings assigned by each of the raters using the video-based qualitative assessment for the 26 subjects in the study. Unweighted kappa statistic was computed for each rater-method pair. The κ values were interpreted according to Altman[21] with values <0.2 indicating poor agreement, 0.21 to 0.40 indicating fair agreement, 0.41 to 0.6 indicating moderate agreement, 0.61 to 0.8 indicating good agreement, and 0.81 to 1 indicating very good agreement. Statistical significance of the κ statistic was determined by $P<0.05$.

RESULTS

Kinematic plots of KPA for the right side of TD children and the affected side of children with hemiplegic type CP, calculated by direct and indirect methods, are shown in Figure 2. For the 32 TD children the mean direct KPA was 1.6 degrees (range, -12.7 to 16.1 degrees); the

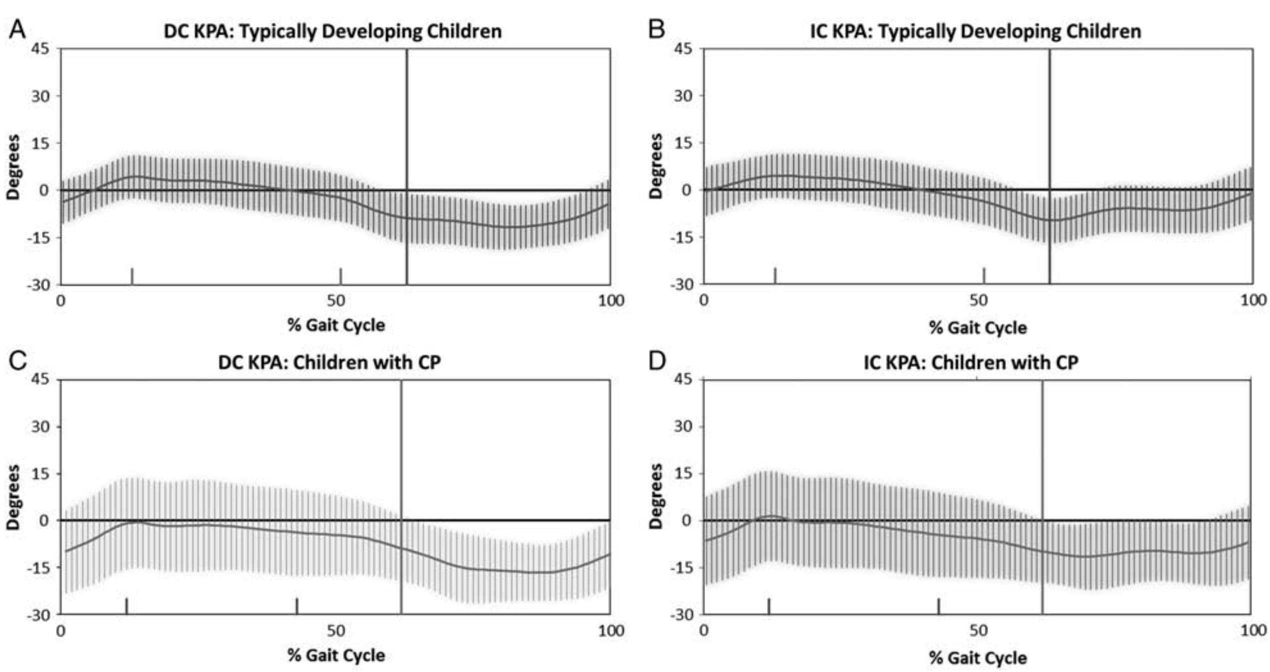

FIGURE 2. Kinematic plots of knee progression angle (KPA). Mean values, ±1 SD. A, Kinematic plot of directly calculated KPA (DC KPA) for 32 typically developing (TD) children. B, Kinematic plot of indirectly calculated KPA (IC KPA) for 32 TD children. C, Kinematic plot of DC KPA for 43 children with cerebral palsy (CP). D, Kinematic plot of IC KPA for 43 children with CP.

Copyright © 2018 Wolters Kluwer Health, Inc. All rights reserved.

mean indirect KPA was 1.5 degrees (range, −13.5 to 15.8 degrees). For the 43 children with CP the mean direct KPA was −3.1 degrees (range, −52 to 32.8 degrees); the mean indirect KPA was −2.5 degrees (range, −52.4 to 34 degrees).

Children with CP had a greater range of KPA than the TD children. RMS analysis (mean ± 1 SD) for the right side of TD children was 1.14 ± 0.43 degrees, and 1.75 ± 1.54 degrees for the affected side of children with CP. The difference in RMS among the 2 groups was statistically, but not clinically, significant ($P = 0.019$). Interrater reliability analysis using ICC (3,1) showed excellent agreement between the 2 methods for the 32 TD children with ICC 0.996 (95% CI, 0.991-0.998), and for the 43 children with CP with ICC 0.992 (95% CI, 0.985-0.996). ICCs for both groups were statistically significant ($P < 0.001$).

Data evaluating the comparison between quantitative and qualitative assessment of KPA in children with CP are summarized in Table 1. There was complete agreement among all 3 examiners for 17 of the 26 cases (65%). There was agreement between 2 of 3 examiners for 9 additional cases (35%).

TABLE 1. Quantitative and Qualitative Assessments of KPA

	Quantitative				Qualitative		
Subject	Direct KPA*	Categorical KPA	Indirect KPA*	Categorical KPA	Rater 1	Rater 2	Rater 3
1	−52.04	E	−52.39	E	E	E	E
2	−23.64	E	−22.13	E	E	N	E
3	−19.83	E	−19.87	E	E	E	E
4	−18.05	E	−16.98	E	E	E	E
5	−16.54	E	−16.49	E	E	E	E
6	−15.37	E	−16.26	E	E	N	E
7	−14.65	E	−9.6	N	N	N	N
8	−12.44	E	−14.84	E	E	E	E
9	−10.33	N	−10.04	N	N	N	E
10	−8.55	N	−8.18	N	N	N	E
11	−5.43	N	−7.6	N	E	I	E
12	−5.59	N	3.59	N	E	E	E
13	−2.88	N	−2.77	N	N	N	N
14	−1.65	N	−1.77	N	N	N	N
15	−1.47	N	−0.24	N	N	N	N
16	−1.17	N	−0.95	N	N	N	N
17	2.57	N	2.59	N	E	N	E
18	4.45	N	5.64	N	N	N	N
19	7.19	N	10.43	N	I	I	I
20	8.9	N	9.53	N	E	N	N
21	13.63	N	14.05	N	I	I	I
22	14.66	I	14.1	I	N	N	N
23	14.42	I	13.32	I	N	N	E
24	19.65	I	18.76	I	I	I	N
25	29.18	I	31.31	I	I	I	I
26	32.78	I	33.98	I	I	I	I

*Values are reported as degrees.

Categorical KPA indicates continous quantitative data categorized as external, neutral, or internal; Direct KPA, directly calculated KPA; E, external; I, internal; Indirect KPA, indirectly calculated KPA; KPA, knee progression angle; N, neutral; Qualitative, video-based observational gait analysis; Quantitative, kinematic calculation.

TABLE 2. Intrarater Reliability of Methods of KPA

	Unweighted κ	κ Strength	SE	95% CI	P†
Rater 1					
Direct KPA	0.525	Moderate	0.140	0.250-0.800	< 0.001*
Indirect KPA	0.585	Moderate	0.132	0.327-0.844	< 0.001*
Rater 2					
Direct KPA	0.509	Moderate	0.146	0.223-0.796	< 0.001*
Indirect KPA	0.563	Moderate	0.144	0.281-0.844	< 0.001*
Rater 3					
Direct KPA	0.410	Moderate	0.142	0.130-0.688	0.003*
Indirect KPA	0.473	Moderate	0.134	0.211-0.735	< 0.001*

*Indicates statistical significant at $P < 0.05$.

†P-value is the significance of the κ statistic for cross-tabulation of each rater-method pair.

CI indicates confidence interval; Direct KPA, directly calculated KPA; Indirect KPA, indirectly calculated KPA; KPA, knee progression angle; κ, kappa statistic.

Direct KPA categories were the same as the rater-determined categories for 49 of 78 observations (63%). For the 8 subjects quantitatively determined to have external KPA, qualitative assessment were correct for 19 of the 24 clinician assessments (79%). Qualitative assessment of KPA for the 13 subjects quantitatively determined to have neutral KPA were correct for 22 of the 39 clinician assessments (56%). For the 5 subjects quantitatively determined to have an internal KPA, qualitative assessments were correct for 8 of the 15 clinician assessments (53%). Intrarater reliability analysis using the unweighted κ statistic showed moderate agreement for all rater-direct method pairs: rater 1-direct KPA κ = 0.525 (95% CI, 0.25-0.8), $P < 0.001$; rater 2-direct KPA κ = 0.509 (95% CI, 0.223-0.796), $P < 0.001$; and rater 3-direct KPA κ = 0.410 (95% CI, 0.13-0.688), $P = 0.003$ (Table 2).

Indirect KPA categories were the same as the rater-determined categories for 52 of 78 observations (67%). For the 7 subjects quantitatively determined to have external KPA, qualitative assessment were correct for 19 of the 21 clinician assessments (90%). Qualitative assessment of KPA for the 14 subjects quantitatively determined to have neutral KPA were correct for 25 of the 42 clinician assessments (60%). For the 5 subjects quantitatively determined to have an internal KPA, qualitative assessment were correct for 8 of the 15 clinician assessments (53%). Intrarater reliability analysis using the unweighted kappa statistic showed moderate agreement for all rater-indirect method pairs: rater 1-indirect KPA κ = 0.585 (95% CI, 0.327-0.844), $P < 0.001$; rater 2-indirect KPA κ = 0.563 (95% CI, 0.281-0.844), $P < 0.001$; and rater 3-indirect KPA κ = 0.473 (95% CI, 0.211-0.735), $P < 0.001$ (Table 2).

DISCUSSION

OGA can be performed when examining a patient in the clinic setting, or from video taken of the subject. In an effort to make OGA more reliable and valid, a number of observational gait scales have been developed.[17,18,22–27]

There has been limited psychometric evaluation of most of these tools. A recent review of OGA tools that can be used for pediatric subjects identified 6 tools following a computerized search of bibliographic databases.[26] Three of the OGA tools included evaluation of the transverse plane rotation of the hip, and in all cases this was inferred from visual assessment of KPA.[17,18,22] The EVGS provided the most explicit technique for determining KPA, based upon the portion of the patella that is visible when the subject is walking toward the observer.[18]

Despite the common use and utility of assessing KPA during OGA, relatively little has been done to quantitatively assess this gait parameter and to determine the accuracy of observational techniques.[15,17,18,28] In this study we have developed and evaluated 2 quantitative techniques for the calculation of KPA. The direct method is the most biomechanically accurate, as it calculates the projection of the knee joint center and lateral knee marker relative to the gait line of progression. Unfortunately, this approach required development of specific software to generate the desired kinematic plots, making it unavailable to motion analysis laboratories that rely on "black box" vendor supplied kinematic software. As a more accessible alternative, the indirect method for the calculation of KPA was developed. This approach is less biomechanically rigorous, but more easily performed, as it uses routinely available pelvic and hip transverse plane rotations to calculate the KPA (ie, the KPA is the sum of pelvic and hip rotation). The difference between RMS calculated for the direct and indirect methods was statistically but not clinically significant, which supports the use of either method based upon availability. The small but statistically significant differences in RMS values are most like the consequence of modeling assumptions related to the calculation of the hip joint center in the indirect method and soft tissue artifact that variably affects both methods.[29] Further evaluation of the strength of agreement between KPA measures calculated by the direct and indirect methods revealed excellent agreement in both the typically developing and hemiplegic CP groups.

The kinematic analyses revealed the contribution of both pelvic and hip rotation to the KPA. With OGA it is often difficult to determine the contribution of the pelvic rotation to the KPA, which may result in inaccurate assessment of the contribution of hip rotation to the KPA. This study did not address the clinician's interpretation of the cause of the KPA, whether from pelvic and/or hip rotation. However, it is clear that kinematic analysis, in addition to OGA, is an essential component in the selection of a surgical intervention to address KPA deviations.

Video-based qualitative assessment of KPA by 3 experienced clinicians showed moderate reliability, with complete agreement among the 3 occurring in only 65% of the cases. The validity of the clinicians' qualitative assessment of KPA, relative to the quantitative direct and indirect methods for calculation of KP, was reflected by 63% and 67% agreement, respectively. Clinical experience with OGA and quantitative gait analysis has been shown to improve the psychometrics of systematic OGA.[28,30] However, the frequent difference in the observed KPA when compared with the calculated KPA found in our study indicates the need for caution when relying on visual assessments for clinical interpretation, and demonstrates the value of adding KPA calculation to standard quantitative kinematic analysis of gait for children with CP.

REFERENCES

1. Carty CP, Walsh HP, Gillett JG, et al. The effect of femoral derotation osteotomy on transverse plane hip and pelvic kinematics in children with cerebral palsy: a systematic review and meta-analysis. *Gait Posture*. 2014;40:333–340.
2. Davids JR, Ounpuu S, DeLuca PA, et al. Optimization of walking ability of children with cerebral palsy. *Instr Course Lect*. 2004;53: 511–522.
3. DeLuca PA, Davis RB III, Ounpuu S, et al. Alterations in surgical decision making in patients with cerebral palsy based on three-dimensional gait analysis. *J Pediatr Orthop*. 1997;17:608–614.
4. Dreher T, Wolf S, Braatz F, et al. Internal rotation gait in spastic diplegia—critical considerations for the femoral derotation osteotomy. *Gait Posture*. 2007;26:25–31.
5. Dreher T, Wolf SI, Heitzmann D, et al. Long-term outcome of femoral derotation osteotomy in children with spastic diplegia. *Gait Posture*. 2012;36:467–470.
6. Gage JR. Orthopaedic treatment of long bone torsions. In: Gage JRSMH, Koop SE, Novacheck TF, eds. *The Identification and Treatment of Gait Problems in Cerebral Palsy*, 2nd ed. London: MacKeith Press; 2009:473–491.
7. Niklasch M, Doderlein L, Klotz MC, et al. Asymmetric pelvic and hip rotation in children with bilateral cerebral palsy: uni- or bilateral femoral derotation osteotomy? *Gait Posture*. 2015;41:670–675.
8. O'Sullivan R, Kiernan D, Walsh M, et al. The difficulty identifying intoeing gait in cerebral palsy. *Ir Med J*. 2013;106:144–145.
9. Ounpuu S. Gait analysis is a viable tool for the assessment of transverse plane motion in children with cerebral palsy. *Dev Med Child Neurol*. 2013;55:878–879.
10. Rethlefsen SA, Healy BS, Wren TA, et al. Causes of intoeing gait in children with cerebral palsy. *J Bone Joint Surg Am*. 2006;88:2175–2180.
11. Wren TA, Lening C, Rethlefsen SA, et al. Impact of gait analysis on correction of excessive hip internal rotation in ambulatory children with cerebral palsy: a randomized controlled trial. *Dev Med Child Neurol*. 2013;55:919–925.
12. Ounpuu S, DeLuca P, Davis R, et al. Long-term effects of femoral derotation osteotomies: an evaluation using three-dimensional gait analysis. *J Pediatr Orthop*. 2002;22:139–145.
13. Schwartz MH, Rozumalski A, Novacheck TF. Femoral derotational osteotomy: surgical indications and outcomes in children with cerebral palsy. *Gait Posture*. 2014;39:778–783.
14. Novacheck TF, Trost JP, Sohrweide S. Examination of the child with cerebral palsy. *Orthop Clin North Am*. 2010;41:469–488.
15. Del Pilar Duque Orozco M, Abousamra O, Church C, et al. Reliability and validity of Edinburgh Visual Gait Score as an evaluation tool for children with cerebral palsy. *Gait Posture*. 2016;49: 14–18.
16. Hillman SJ, Hazlewood ME, Loudon IR, et al. Can transverse plane rotations be estimated from video tape gait analysis? *Gait Posture*. 1998;8:87–90.
17. Kawamura CM, de Morais Filho MC, Barreto MM, et al. Comparison between visual and three-dimensional gait analysis in patients with spastic diplegic cerebral palsy. *Gait Posture*. 2007;25: 18–24.
18. Read HS, Hazlewood ME, Hillman SJ, et al. Edinburgh Visual Gait Score for use in cerebral palsy. *J Pediatr Orthop*. 2003;23:296–301.
19. Palisano R, Rosenbaum P, Walter S, et al. Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Dev Med Child Neurol*. 1997;39:214–223.
20. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med*. 2016;15: 155–163.

21. Altman DG. *Practical Statistics for Medical Research*. London: Chapman and Hall; 1991.
22. Araujo PA, Kirkwood RN, Figueirdo EM. Validity and intra- and inter-rater reliability of the observational gait scale for children with spastic cerebral palsy. *Rev Bras Fisioter*. 2009;13:267–273.
23. Dickens WE, Smith MF. Validation of a visual gait assessment scale for children with hemiplegic cerebral palsy. *Gait Posture*. 2006;23: 78–82.
24. Harvey A, Gorter JW. Video gait analysis for ambulatory children with cerebral palsy: why, when, where and how! *Gait Posture*. 2011;33:501–503.
25. Mackey AH, Lobb GL, Walt SE, et al. Reliability and validity of the Observational Gait Scale in children with spastic diplegia. *Dev Med Child Neurol*. 2003;45:4–11.
26. Rathinam C, Bateman A, Peirson J, et al. Observational gait assessment tools in paediatrics—a systematic review. *Gait Posture*. 2014;40:279–285.
27. Toro B, Nester CJ, Farren PC. The development and validity of the Salford Gait Tool: an observation-based clinical gait assessment tool. *Arch Phys Med Rehabil*. 2007;88:321–327.
28. Ong AM, Hillman SJ, Robb JE. Reliability and validity of the Edinburgh Visual Gait Score for cerebral palsy when used by inexperienced observers. *Gait Posture*. 2008;28:323–326.
29. Schwartz MH, Rozumalski A. A new method for estimating joint parameters from motion data. *J Biomech*. 2005;38:107–116.
30. Viehweger E, Zurcher Pfund L, Helix M, et al. Influence of clinical and gait analysis experience on reliability of observational gait analysis (Edinburgh Gait Score Reliability). *Ann Phys Rehabil Med*. 2010;53:535–546.

