Pediatric Physical Therapy
Beyond the Read

CLINICAL PRACTICE GUIDELINE

Three-Dimensional Instrumented Gait Analysis for Children With Cerebral Palsy: An Evidence-Based Clinical Practice Guideline

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Background: Children with cerebral palsy (CP) who walk have complex gait patterns and deviations often requiring physical therapy (PT)/medical/surgical interventions. Walking in children with CP can be assessed with 3-dimensional instrumented gait analysis (3D-IGA) providing kinematics (joint angles), kinetics (joint moments/powers), and muscle activity.

Purpose: This clinical practice guideline provides PTs, physicians, and associated clinicians involved in the care of children with CP, with 7 action statements on when and how 3D-IGA can inform clinical assessments and potential interventions. It links the action statement grades with specific levels of evidence based on a critical appraisal of the literature.

Conclusions: This clinical practice guideline addresses 3D-IGA's utility to inform surgical and non-surgical interventions, to identify gait deviations among segments/joints and planes and to evaluate the effectiveness of interventions. Best practice statements provide guidance for clinicians about the preferred characteristics of 3D-IGA laboratories including instrumentation, staffing, and reporting practices.

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Summary of Action Statements

(I) **B. Informing Orthopedic Surgical Interventions**: Physical therapists, physicians, and associated clinicians should recommend 3D-IGA when a child with CP who walks with or without an assistive mobility device is considered for orthopedic surgery to improve gait. (Evidence Quality: **II**, Rec. Strength: **Moderate**)

(II) **B. Gait Deviation Analysis**: Physical therapists, physicians, and associated clinicians should recommend 3D-IGA when a child with CP presents with gait dysfunction and there is a need to identify, quantify, and differentiate deviations among individual segments/joints and planes (sagittal, coronal, and transverse). (Evidence Quality: **II**, Rec. Strength: **Moderate**)

(III) **B. 3D-IGA to Evaluate Biomechanical Outcomes**: When physical therapists, physicians, and associated clinicians need to evaluate biomechanical aspects of gait related to an intervention for children with CP, they should recommend baseline and post-intervention

WHAT THIS EVIDENCE ADDS

Current evidence: Numerous research studies have incorporated 3-dimensional instrumented gait analysis (3D-IGA) for children with impairments affecting walking. This research has been broadly summarized in a scoping review regarding the use of 3D-IGA for the management of walking in children with cerebral palsy as well as 2 systemic reviews of the clinical efficacy of instrumented gait analysis.[1-3]

Gap in the evidence: The scoping and systemic reviews do not provide guidelines for pediatric physical therapists and associated clinicians about how or when to incorporate the use of 3D-IGA in the care of children with cerebral palsy.

How does this study fill this evidence gap? These are the first clinical practice guidelines related to use of 3D-IGA in the management of walking for children with cerebral palsy. Guidelines address whether assessment that includes 3D-IGA changes treatment decisions and produces better outcomes compared with a plan of care that does not include 3D-IGA. These guidelines also address what information 3D-IGA provides independent from typical clinical evaluations and if 3D-IGA can be an appropriate tool to evaluate the biomechanical effects of interventions aimed at improving walking function. Finally, recommendations for the equipment, staffing, and reporting for 3D-IGA are described.

Implication of all the evidence to clinicians: Pediatric physical therapists and associated clinicians now have guidance on when assessment with 3D-IGA is appropriate for children with cerebral palsy based on evidence that has been rated on quality and summarized.

3D-IGA. (Evidence Quality: **III**, Rec. Strength: **Weak upgraded to Moderate** for consistent results)

(IV) **C. Non-Surgical Interventions**: Physical therapists, physicians, and associated clinicians may recommend 3D-IGA to inform non-surgical interventions for children with CP with gait dysfunction whose progress from rehabilitative interventions and conservative management has plateaued or shown substantial deterioration. (Evidence Quality: **III**, Rec. Strength: **Weak**)

(V) **P. Instrumented Gait Analysis Equipment**: When 3D-IGA is recommended for children with CP to assess gait patterns, physical therapists, physicians, and associated clinicians should recommend gait laboratories that can collect 3-dimensional kinematic, kinetic, and electromyography (EMG) data. (Evidence Quality: **V**, Rec. Strength: **Best Practice**)

(VI) **P. Interdisciplinary Team Approach**: When 3D-IGA is recommended for children with CP to assess gait patterns, physical therapists, physicians, and associated clinicians should recommend a 3D-IGA laboratory that has an interdisciplinary team approach. (Evidence Quality: **V**, Rec. Strength: **Best Practice**)

(VII) **P. Comprehensive Reports**: When 3D-IGA is recommended for children with CP to assess gait patterns, physical therapists, physicians, and associated clinicians should recommend 3D-IGA laboratories that provide comprehensive, timely, and interdisciplinary reports including: (a) referral source and reason for referral; (b) diagnosis including Gross Motor Function Classification System (GMFCS) level; (c) primary concerns or goals of the child, family, and health care professionals including physical therapists; (d) pertinent past medical history; (e) current orthoses and adaptive equipment; (f) findings of physical exam; (g) documentation of 3D-IGA results; (h) limitations in conducting the assessment and or technical issues; (i) interpretation of findings by licensed clinician(s) (eg, MD and/or PT); and (j) suggestions for interventions by licensed clinician(s). (Evidence Quality: **V**, Rec. Strength: **Best Practice**)

INTRODUCTION

The Academy of Pediatric Physical Therapy (APPT) of the American Physical Therapy Association (APTA) supports the development of evidence-based clinical practice guidelines (CPG) as a service to its members. The APPT appointed the Guideline Development Group (GDG) to develop a CPG for physical therapists (PTs) and other healthcare providers involved in the management of children with cerebral palsy (CP) describing the utility of 3-dimensional instrumented gait analysis (3D-IGA) in the clinical management of children who walk with dysfunction related to (CP). The GDG included pediatric PTs, clinical researchers, and a biomedical engineer; content experts in the areas of pediatric PT, gait/motion analysis, and systematic review methodology.

Purpose of the CPG

This CPG aims to help PTs, physicians, and associated clinicians involved in the care of children with CP to determine how 3D-IGA can be used to guide decision making about potential examinations and interventions, and to improve clinical outcomes. The guideline is focused on the use of 3D-IGA in the management of children with CP who can walk with or without an assistive mobility device and who have gait dysfunction. Throughout this guideline, 3D-IGA refers to analysis of 3-dimensional kinematic data from a motion capture system; it may be accompanied by related measurement technologies including force plates (kinetics) and electromyography (EMG), often done simultaneously.

Scope of the Guideline

This CPG aims to address questions for PTs, physicians, and associated clinicians with regard to the utility of 3D-IGA in the clinical management of children who walk with dysfunction related to CP. PTs may be asked to consult with families about when 3D-IGA might be appropriate. This CPG is focused on understanding how and when 3D-IGA can be useful in the clinical decision-making process. This CPG does not consider the specific testing conditions or technological details to analyze a specific child's walking performance. This CPG suggests (a) the minimum set of equipment/instruments that should be available for 3D-IGA for management of walking in children with CP; (b) the characteristics of the personnel and laboratories that perform 3D-IGA; and (c) what should be included in a comprehensive 3D-IGA report. The reader should note that the terms "walking" and "gait" are interchangeable except when referring to industry-related terms defined in the glossary, specific tests, processes and organizations.

Statement of Intent

This CPG is intended to help clinicians learn about the utility of gait analysis for the clinical management of children with CP. This CPG also intends to guide and inform PTs, family members, educators, physicians, orthotists, engineers, biomechanists, kinesiologists, and other healthcare providers about the utility of 3D-IGA in the management of children who walk and with CP. This CPG was not developed to be construed as or to serve as a standard of care, and adherence to the action statements will not guarantee a successful outcome with every child. Guideline action statements may not be inclusive of other appropriate methods of care aimed at the same outcomes or exclude other acceptable methods of care aimed at the same results. This CPG is a summary of action statements that are supported with current published evidence or standards of care. The CPG has been reviewed by an interdisciplinary group of interested people representing physical therapy, orthopedic surgery, engineering, kinesiology, educators, parents, and adults with CP. The action statements are guidelines only, not mandates. The ultimate decision or judgment regarding a particular clinical procedure or a specific plan of care must be made by the appropriate health care practitioner(s) in consultation with the child and family with regard to the child's clinical data, the diagnostic and treatment options available, the clinician's scope of practice and clinical expertise, and the child's values, expectations, and preferences. However, it is recommended that significant departures from accepted guidelines be documented in children's records at the time the relevant clinical decision is made.

METHODS

Determining Priority Content

The GDG conducted a needs assessment survey based on current 3D-IGA practice,[1] completed a scoping review to understand the literature,[2] solicited attendee feedback at the 2018 and 2019 meetings of the Gait and Clinical Movement Analysis Society (GCMAS), the primary professional organization focused on 3D-IGA in North America, and consulted with experts involved in CPG development and use of 3D-IGA in the management of children with CP.

The needs assessment survey identified the priorities of the clinical and research communities involved with 3D-IGA for children with CP.[1] The survey was completed by 52 PTs and 44 other professionals involved with the care of children with CP. It informed development of the following 7 questions for the CPG relevant to the management of children with CP-related gait dysfunction: (1) When a child is considered for orthopedic surgery related to their gait dysfunction, does a plan of care that includes 3D-IGA change treatment decisions and produce better outcomes compared with a plan of care that does not include 3D-IGA? In this context, is 3D-IGA cost effective relative to other examination methods? (2) Can 3D-IGA provide information independent from typical clinical evaluations that identifies, quantifies and differentiates deviations among individual segments/joints and planes (sagittal, coronal, and transverse) underlying a child's gait dysfunction? (3) Is 3D-IGA an appropriate tool to evaluate the biomechanical and neuromuscular effects of interventions aimed at improving walking for children with CP who walk? (4) When a child is considered for a substantial new episode of non-surgical treatment related to the child's gait dysfunction, does including 3D-IGA when compared with not including 3D-IGA change treatment decisions and produce better outcomes following non-surgical interventions? (5) What minimum set of equipment/instruments should be available for children with CP who are referred for 3D-IGA? (6) What should be the composition and expertise of interdisciplinary personnel who plan, perform, and interpret 3D-IGA? (7) What information should be included in a comprehensive 3D-IGA report?

Literature Search

The initial literature search for this CPG was conducted in the context of a previously published scoping review and 2 systematic reviews on the clinical efficacy of IGA.[2-4] Two health sciences librarians assisted with establishing database specific optimal and reproducible search strategies to generate a comprehensive search. The initial search was completed in December 2019, was updated periodically, and included studies published through September 2022. Searches were performed using the following databases: Ovid/MEDLINE, EMBASE, the Cumulative Index to Nursing and Allied Health Literature (CINAHL), the Physiotherapy Evidence Database (PEDro), the Cochrane Database of Systematic Reviews, and the Cochrane CENTRAL database. Search terms included closely related terms, and combinations of terms: gait analysis, instrumented gait analysis, clinical gait analysis, kinematics, kinetics, electromyography, 3-dimensional motion capture, force plate, cerebral palsy, monoplegia, diplegia, athetoid, spastic, hypotonic, ataxic, gait, walking, ambulation, locomotion, child, adolescent, girl, boy, pre-school, school-age, high school, middle school, teen, youth, pediatric (Supplemental Digital Content 1 available at http://links.lww.com/PPT/A520).

Studies were eligible for inclusion in this CPG if they met the following criteria: (a) peer-reviewed research, (b) sample included children with CP (the term "children" is operationally defined as anyone up to 21 years of age), (c) investigated using 3D-IGA in treatment or assessment of gait dysfunction, and (d) in English. Exclusion criteria included: the article was a review, commentary, or conference abstract. Additional searches, including hand-searching, were performed, to identify resources for best practices in motion analysis laboratory quality and accreditation standards related to personnel, equipment, cost, and reporting.

Study Selection

A literature search was defined in a scoping review and updated for the CPG in September 2022. Together 2179 citations were identified and screened for inclusion; they were simultaneously categorized regarding the CPG question to which they pertained. Reliability for inclusion and categorization were established among the 6 reviewers as described in the scoping review.[2] Briefly, 6 reviewers independently reviewed and discussed 5 groups of 20 citations and abstracts to establish consensus and refine the checklist for inclusion and categorization. This was followed by independent blind assessment by pairs of reviewers for approximately half of the citations (~1050), then independent assessment of about 175 remaining citations by each of the 6 reviewers. Two authors conducted a final round of random checks of the selection and categorization judgments on over 500 citations to assure overall consistency. Overall, 969 studies were identified as relevant to 3D-IGA for the management of children with CP-related gait dysfunction; a subset of these are cited in the supporting evidence sections.

Data Extraction

Data extraction for articles relevant to the CPG questions followed the procedures suggested by the APTA Clinical Practice Guideline Manual 2018.[5] This included having a methodologist adapt the forms suggested in the CPG manual and from the Covidence tool (Veritas Health Innovation)[6] for the various CPG questions. Along with basic design features, specific criteria to assess study quality and results were extracted. For experimental studies, pairs of GDG members extracted the data independently and discussed discrepancies. If discrepancies remained, a third GDG member assessed the study and consensus via discussion resolved the issue. For the cross-sectional and cohort studies, pairs of GDG members extracted data for 2 randomly chosen groups of 20 studies each to reach consensus on interpretation. Subsequently, GDG members individually conducted data extraction on approximately 50 remaining articles each, with ambiguities resolved by discussion with the GDG partner or a third GDG member as needed.

Critical Appraisal Process

Experimental studies for CPG question 1, Evaluating orthopedic surgical interventions were appraised with the Critical Appraisal Tool for Experimental Interventions (CAT-EI V1.2).[5] Two GDG members independently appraised study quality with 93% reliability on the 24 orthopedic surgical intervention studies. For CPG question 2, independent information from clinical measures, the Appraisal tool for Cross-Sectional Studies[7] was applied to 20 articles randomly chosen from the included studies. Reliability of over 90% was achieved on the individual items and total score for these articles amongst the 4 reviewers. The remaining 109 cross-sectional studies were appraised by 1 of the reviewers, with discussion among pairs of reviewers to categorize uncertainties. Literature addressing CPG question 3, 3D-IGA to evaluate biomechanical outcomes was not rated for the quality of the research design. That CPG question aimed to describe the utility of using 3D-IGA as a measurement tool to quantify changes, not to determine the effectiveness of the study's intervention. Hence, we assessed whether any of its 3D-IGA outcome measures were responsive to the intervention by assessing whether at least 1 3D-IGA measure supported a statistically significant difference. This methodological choice is discussed further in the Supporting Evidence for Action Statement III. For CPG question 4, nonsurgical interventions, the relevant literature consisted of intervention studies, thus, they were assessed using the CAT-EI in the same method as for CPG question 1. Since the 5th, 6th, and 7th CPG questions addressed standards for best practices in equipment, personnel, and reporting, evidence was derived from clinical perspectives, accreditation, and other guidance statements rather than from empirical studies.

Of the 24 orthopedic surgical intervention publications, 2 were high quality, 10 acceptable, 7 low quality, and 5 were unacceptable based on their CAT-EI ratings. Many of these studies were multi-year retrospective investigations of patient registries from large and well-established gait labs. As such, randomization, *a-priori* power analyses or inclusion of a control group were not used. Most studies included rigorous inclusion/exclusion criteria, standardized and validated protocols for measuring and analyzing data, and experienced interdisciplinary teams to conduct the investigation and interpret the data. Most studies minimized recruitment bias by including a consecutive sample of children referred to individual labs. There was clear adherence to the established protocol as methods describing the biomechanical models for processing 3D-IGA data were either detailed or referenced.

The 129 studies on deviations of segments/joints and planes (sagittal, coronal, and transverse) were assessed using the Appraisal Tool for Cross-Sectional Studies[7] with the following adaptations. Three items were assigned a value of *Not Reported* as they did not apply to the descriptive nature of the studies: were measures undertaken to address and categorize non-responders? Does the response rate raise concerns about non-response bias? If appropriate, was information about non-responders described? The item regarding funding sources was reverse coded so that authors who reported funding without conflicts of interest received a positive score. Given these adaptations, the total possible score was 17 rather than 20; 90 were rated as high quality, 36 were moderate, and 3 were low quality.

TABLE 1
Levels of Evidence and Action Statement Grade Criteria

Level of evidence	Preponderance of benefit or harm	Balance of benefit or harm	Level of obligation to follow the action statement	Level of obligation against an action	Potential letter grades based on highest level of evidence
I	Strong	Option	Must or should	Must not or should not	A or strong
II	Moderate	Option	Should	Should not	B or moderate
III	Weak	Option	May	May not	C or weak
IV	Weak	Option	May	May not	C or weak
V	Option	No recommendation	May	May not	P or practice
Best practice	Varies	No recommendation	Should or may	Should not or may not	P or practice

Only 2 studies (4 publications) addressed CPG question 4, nonsurgical interventions. Three articles were rated high quality based on the CAT-EI, and 1 was rated as acceptable; interrater agreement for these articles was 97%.

Determination of Action Statements

The BRIDGE-Wiz software[8] was used to assure that action statements aligned with the Institute of Medicine's standards for transparency through its process and the template of headings.[9]

The evidence quality and grade for each action statement were assigned through consensus of the GDG (Tables 1 and 2) based on the APTA Clinical Practice Guideline Manual.[5] This included consideration of critical appraisal of results, the extent to which the set of available studies specifically answered the CPG question (indirectness as defined by GRADE), consistency of results, and volume of supporting evidence.[10]

External Review Process

A CPG Advisory Board consisted of interested parties with experience in 3D-IGA, including professionals, children, and families of individuals who experienced 3D-IGA (Supplemental Digital Content 2 available at http://links.lww.com/PPT/A521). Roles of the Advisory Board were to review and comment on the CPG scope, CPG questions, first draft review, and second revised draft prior to publication. The second draft was posted for public comment through the APPT *Milestones* newsletter. An electronic newsletter was sent to APPT members, literature appraisers, and clinicians who inquired about the CPG during development. The GDG recorded and considered comments from each round of reviews to edit the CPG prior to final submission for publication.

BACKGROUND

Cerebral Palsy

Cerebral palsy describes a group of disorders in the development of movement and posture, causing activity limitations and participation restrictions, attributed to non-progressive disturbances that occurred in the developing fetal or infant brain.[11] CP is the most common neuromotor disorder among children with an overall prevalence 2.1 cases per 1000 live births.[12] The motor disorders seen in children with CP are often accompanied by disturbances of sensation, perception, cognition, communication, behavior, and seizure disorders and by secondary musculoskeletal complications.[11,13,14] CP can be described by the types of motor impairment including spastic, dystonic, dyskinetic, ataxic, hypotonic, rigid, or mixed type[15] or according to the distribution of impairments as unilateral including hemiplegia, bilateral including diplegia, or total-body involvement (eg, quadriplegia, tetraplegia).[14] Functional motor skills of children with CP are also classified using the Gross Motor Function Classification System (GMFCS),[16] a 5-level ordinal measure with foci on posture and mobility. Level I represents the highest functional motor ability and Level V the lowest; motor skills expected for various age groups are described for each GMFCS level.[16,17]

Children with CP often have complex gait dysfunction which can limit activities and participation in family, school, social, and workplace settings and may result in significant deformities that require complex medical, rehabilitative, and surgical interventions. Approximately, 70% of persons up to age 21 years,[18,19] walk with or without an assistive mobility device (ie, walker, crutches, etc.). Altered walking may result in tripping/falling, fatigue, limited participation in activities, joint pain, segment/joint deformities and premature development of osteoarthritic changes.[20-22] Children with CP and their families often have concerns about the appearance and/or quality of their walking (eg, limping, stiff knee(s), flexed knee(s), in-toeing, toe walking, etc.), tripping and falling, their speed and endurance, as well as pain.[23-25] Gait patterns in children with CP vary depending on the type of CP, distribution of impairments (hemiplegia, diplegia, and quadriplegia), severity, available range of motion and flexibility, strength, muscle tone involvement, selective control, dynamic balance, involvement at joints, segments and planes (sagittal, coronal, and transverse), and associated orthopedic deformities. Atypical gait pattern descriptions in children with bilateral and unilateral involvement may involve sagittal plane deviations[26-28]; however, multi-segment/joint deviations in the coronal and transverse planes as well as additional compensatory gait deviations can further affect gait pattern.[29-32] Common gait patterns seen in children with CP include, but are not limited to:

- Equinus gait: the foot/ankle is in plantar flexion resulting in toe walking.
- Jump gait: the foot/ankle is in plantar flexion and the knees are flexed.

TABLE 2
Level of Evidence Complete Definitions

Level of evidence	Intervention/ prevention	Pathoanatomic/ risk/clinical course/prognosis/ differential diagnosis	Diagnosis/ diagnostic accuracy	Prevalence of condition/ disorder	Exam/ outcomes
I. Evidence obtained from high-quality systematic reviews, diagnostic studies, prospective studies, or randomized controlled trials (RCTs)	Systematic review of high-quality RCTs (a)	Systematic review of prospective cohort studies High-quality prospective cohort study (b)	Systematic review of high-quality diagnostic studies High-quality diagnostic study with validation (c)	Systematic review of high-quality cross-sectional studies High-quality cross-sectional study (d)	Systematic review of prospective cohort studies High-quality prospective cohort study
II. Evidence obtained from lesser-quality diagnostic studies, prospective studies, or RCYs (eg, weaker diagnostic criteria and reference standards, improper randomization, no blinding, less than 80% follow-up)	Systematic review of high-quality cohort studies High-quality cohort study (b) High-quality outcomes research High-quality quasi-experimental study (g) High-quality single-subject design (h) Lower-quality RCT	Systematic review of retrospective cohort studies Lower-quality prospective cohort study High-quality retrospective cohort study Consecutive cohort study Outcomes study or ecological study (f)	Systematic review of exploratory diagnostic studies or consecutive cohort studies High-quality exploratory diagnostic study Consecutive retrospective cohort study	Systematic review of studies that allows relevant estimate Lower-quality cross-sectional study	Systematic review of lower-quality prospective cohort studies Lower-quality prospective cohort study
III. Case-controlled studies or retrospective studies	Systematic review of case-controlled studies High-quality case-controlled study Outcomes study or ecological study (f) Lower-quality cohort study	Lower-quality retrospective cohort study High-quality cross-sectional study case-controlled study	Lower-quality exploratory diagnostic study Nonconsecutive retrospective cohort study	Local nonrandom study	High-quality cross-sectional study
IV. Case series	Case series	Case series	Case-controlled study		Lower-quality cross-sectional study
V. Expert opinion	Expert Opinion	Expert Opinion	Expert Opinion	Expert Opinion	Expert Opinion

(a) High quality includes RCT>80% follow-up; blinding; appropriate randomization procedures. (b) High-quality or dramatic effect cohort study includes >80% follow-up. (c) High-quality diagnostic study includes consistently applied reference standard and blinding. (d) High-quality prevalence study is a cross-sectional study that uses a local and current random sample or censuses. (e) Weaker diagnostic criteria and reference standards, improper randomization, no blinding, <80% follow-up may add threats to bias and validity. (f) High-quality outcome or ecological studies use instrumental variable(s) or other control for confounding factors. (g) High-quality comparative study without random assignment to groups. (h) Must have a minimum of "a" and "b" phase.

- Apparent equinus gait: toe walking due to knee flexion, not excessive ankle/foot plantar flexion.
- Crouch gait (with and without inflexible knee): the hips and knees are flexed and the ankles are dorsiflexed, or the forefoot is dorsiflexed relative to the hindfoot (ie, flatfoot with midfoot instability) in stance.
- Asymmetrical gait: may include some combination of gait patterns.
- Scissor gait: legs cross when walking which can come from increased internal hip rotation or hip adduction.
- Rotational malalignment: excessive femoral anteversion or retroversion and/or tibial internal or excessive external torsion and/or foot malalignment resulting in either in-toeing, out-toeing, or even a neutral foot progression angle (ie, miserable mal-alignment, or pelvic rotation asymmetry).

Instrumented Analysis of Gait

There are various ways to assess gait dysfunction in children with CP including observational analysis of gait,

standardized rating scales, 2-dimensional (2D) digital video recording, mobile device software applications, temporal-spatial measurement of footfalls, use of isolated body worn sensors, eg, foot pressure sensors or inertial sensors, and 3D-IGA. Unlike simpler forms of analysis, such as observational analysis or 2D motion analysis, only 3D-IGA provides a comprehensive analysis and assessment of typical and pathological walking. 3D-IGA is used to identify specific gait deviations and possible causes of atypical gait patterns, analyze how specific gait deviations influence function, understand typically developing walking, guide decision making about intervention strategies, and evaluate treatment outcomes.[33-35]

3D-IGA provides detailed information on kinematics (spatiotemporal parameters, joint positions, and motions), and often includes simultaneous capture of kinetics (joint forces, moments, and powers) in the child without assistive devices or external support and muscle activity (via EMG). 3D-IGA measures sagittal, coronal, and transverse plane motions and accounts for the relative positions of the joints and segments in 3D. 2D observational analysis is neither sensitive nor reliable enough to assess the complex gait patterns of children with CP.[36,37] 2D gait analysis cannot account for movements not aligned with the point of view. For example, the sagittal plane position and motion of the knee will be underestimated if there is simultaneous internal hip rotation, a common walking problem in persons with CP. In the frontal plane, with internal hip rotation and knee flexion, 2D analysis improperly identifies this situation as valgus. 3D gait analysis defines joint and segment angles in all 3 planes of motion and thus documents anatomically relevant joint angles.

Optical motion capture remains the preferred technology for generating 3D kinematics. Recent technology advances have led to other devices, such as inertial measurement units and markerless motion capture systems. However, these technologies are still developing and require further assessment before use in clinical 3D kinematics analysis. 3D kinematic analysis traditionally uses active or passive reflective marker set(s) and optical cameras to track the 3D location of the marker trajectories over the course of movement. A biomechanical model then uses the marker positions to determine the 3D segment position and orientation, and joint angles are derived from the orientation of relevant segments.[38] Kinematic data provide dynamic angular measurements of the different joints and body segments across the gait cycle. The kinematic data for each segment/joint and plane (sagittal, coronal, and transverse) can be displayed as a series of graphs for a single (or average) gait cycle. In addition, spatiotemporal gait parameters can be calculated to include measurements of gait speed, step and stride length, step width, and cadence.

Kinetic analysis requires that at least 1 force platform be included in the 3D-IGA setup to measure 3D ground reaction forces. Kinetic data are computed using inverse dynamics and are possible when kinematic data are collected synchronously with force plate data. The most commonly used kinetic data in the assessment of gait dysfunction in CP are the sagittal and coronal plane hip, knee and ankle joint moments, and powers. Kinetic data are difficult to collect when children have steplengths too short to have 1 foot on the plate at a time. Kinetic data also cannot be calculated when children use assistive mobility devices that share the load of body weight (unless the assistive devices are also instrumented). The kinetic data for each joint can also be displayed as a series of graphs of a single gait cycle.

Electromyography is used to measure muscle activity that underlies motion. EMG uses sensors placed over the surface of target muscles (ie, surface electrodes), or sensors inserted within the targeted muscles (ie, fine wire electrodes), to record electrical signals from activated muscle fibers. For children with CP, 3D-IGA typically uses surface electrodes. EMG is the only way to confirm what and when muscles are contracting during walking. EMG combined with 3D motion analysis system is used to measure muscle activation and timing during walking. The pattern, timing, and amplitude of muscle activation can be displayed as a set of graphs for a single or series of gait cycle(s).[33,39-42]

Clinical Management of Children with Cerebral Palsy

There are no curative treatments for the neurological disturbances leading to motor dysfunction associated with CP, either through surgical, pharmaceutical, or other known methods. The current management of movement limitations from CP includes medical or surgical treatment, orthoses, and rehabilitation. Medical management of seizures and spasticity may involve oral medications, intrathecal medications, or injections. Orthopedic surgical procedures to address contractures, bony alignment issues, spasticity, and pain, include muscle/tendon lengthenings/releases and transfers, osteotomies (femur and tibia rotations, foot, extension osteotomies), joint fusion, selective dorsal rhizotomy, pelvic and femur osteotomies for hip subluxation, and scoliosis surgeries.[43]

Rehabilitation for children with CP includes a wide range of approaches, such as therapeutic exercise and activities, hands-on and manual techniques, bracing, serial casting, electrical stimulation, mechanically assisted gait training using assistive mobility devices or treadmills, and augmented reality technology. The variability, complexity, and dynamic nature of CP contribute to individualized treatment approaches with variable outcomes. While there is growing evidence to aid the clinician in selection of primary and adjuvant interventions, including recent systematic reviews investigating the effectiveness of some therapeutic interventions,[43-45] comprehensive rehabilitative decision making for children with CP remains poorly studied. This CPG focuses on the use of 3D-IGA to enhance the overall management of children with CP and have gait dysfunction. The CPG does not describe or assess the efficacy of specific physical therapy interventions for children with CP.

ACTION STATEMENTS

Action Statement I: Informing Orthopedic Surgical Interventions

B. Physical therapists, physicians, and associated clinicians should recommend 3D-IGA when a child with CP who walks

with or without an assistive mobility device is considered for orthopedic surgery to improve walking. (Evidence Quality: **II**, Rec. Strength: **Moderate**)

Aggregate Evidence Quality

Level II based on 2 moderate quality randomized controlled trials (RCTs) reported in 3 publications[46-48] and 8 low quality quasi-experimental studies

Benefits

- Conducting 3D-IGA prior to planning orthopedic surgery may identify children who will not benefit from orthopedic surgery.
- Conducting 3D-IGA prior to planned orthopedic surgery informs the selection of and dosing of surgical procedures to improve walking.
- When 3D-IGA recommendations are followed, postoperative outcomes are improved across International Classification of Functioning, Disability and Health domains.
- Over a lifetime, conducting 3D-IGA prior to planned surgeries may reduce the frequency and lifetime costs of surgeries.
- Conducting 3D-IGA prior to planned orthopedic surgery may increase family confidence in the benefits of that surgery.

Risk, Harm, Cost

- Conducting 3D-IGA can be expensive and third-party coverage varies.
- Access to 3D-IGA labs may be limited in some geographic areas.
- Families and children may need to devote substantial time and effort for travel, to attend 3D-IGA session, to wait for data processing and evaluation, and to attend additional appointments that may delay implementation of orthopedic surgical treatment.

Benefit-Harm Assessment

Preponderance of benefit

Value Judgments

None

Intentional Vagueness

The CPG does not endorse any brand or constellation of equipment, modeling, protocol, or evaluative processes for 3D-IGA. While 3D-IGA action statements are designed to aid surgical planning, actual surgical procedures are determined by many factors, such as child/family goals, the surgical techniques, surgeon experience, postoperative rehabilitation approaches, and intended surgical outcomes.

Role of Child/Family Preferences

Families should have a basic understanding of 3D-IGA processes to inform their decision making and help explain the purpose and testing process to their child. Children and families should participate in shared decision making with their clinicians regarding the outcome of 3D-IGA to establish realistic goals and expectations. Ultimately, it is up to the family, the treating surgeon and the interdisciplinary team to reconcile recommendations derived from 3D-IGA evaluation in the plan of care.

Exclusions

Children who do not walk (GMFCS Levels IV–V), children who require gait trainers to complete 3D-IGA, children who cannot follow simple directions due to age, or children with cognitive or behavioral limitations that would prevent completion of gait analyses may not be appropriate for referral. If a child does not have goals or a prognosis to improve walking, 3D-IGA should not be used.

Quality Improvement

Integration of 3D-IGA results with consideration of orthopedic surgery improves walking outcomes for children who walk with CP and reduces unnecessary surgeries.

Implementation and Audit

Share the 3D-IGA CPG with physicians and other health care professionals to increase awareness of the action statements.

Develop a list of 3D-IGA labs in the geographic area who have physicians or surgeons affiliated with the gait lab to expedite referrals for 3D-IGA and possible orthopedic surgical interventions.

Develop consumer friendly supplements for parents and children about 3D-IGA and how it may assist in orthopedic surgical decision making.

Physical therapy documentation should include information supporting the reason for referral for 3D-IGA along with family or physician reported plans for orthopedic surgery.

Supporting Evidence and Clinical Interpretation

Nine studies aimed to identify whether 3D-IGA changed orthopedic surgical planning for children with CP.[46,49-56] All supported that adding 3D-IGA to the clinical examination findings influenced orthopedic surgical decision making. Eight of those 9 studies addressed whether use of 3D-IGA changed the specific orthopedic surgical procedures planned, such as including or eliminating a hamstring lengthening.

TABLE 3

Changes in Orthopedic Surgical Treatment Recommendation after 3D-IGA by Anatomy

Study	Type or location of orthopedic surgery						
	Psoas	Hip adductors	Hamstrings	Rectus femoris	Gastrocnemius/soleus	FDRO	TDRO
Cook, 2003[49]	More	Less	Less	More	Less	Less	Less
DeLuca, 1997[50]	Less	Less	Less	More	More	Less	Less
Ferrari, 2015[51]		Less	Less		Less	More	
Kay, 2000[52]	More	Less	Less	Less	More	Less	Less
Lofterod, 2007[54]	More	Less	Less	More	Less	Less	Less
MacWilliams, 2016[55]			Less				
Wren, 2013[56]		More	More	Less	Less	More and Less	More
Wren, 2011[46]					More and Less		

Abbreviations: FDRO, femoral derotational osteotomy; TDRO, tibial derotational osteotomy.

Findings are summarized descriptively according to whether the number of surgeries reported increased (More), decreased (Less) or increased for some procedures and decreased for others (More and Less) when 3D-IGA was included in the surgical planning.

Orthopedic Surgical Planning: One RCT[46] compared the ultimate orthopedic surgery performed in a group that used 3D-IGA in the surgical planning algorithm to a control group that did not use 3D-IGA for surgical planning. In both groups, the ultimate surgery performed was altered from the original plan given new clinical information, such as radiographs and reassessment.[46] This RCT found a significantly greater change in orthopedic surgical planning when 3D-IGA was applied than in the control condition. When 3D-IGA did not support a planned orthopedic surgical procedure, surgical procedures were eliminated more frequently than in the control group; when 3D-IGA supported a surgical procedure, surgical procedures were added more frequently than in the control group. Finally, when 3D-IGA supported previously planned orthopedic surgery, surgery occurred more frequently in the 3D-IGA group than in the control group (91% vs 70%, $P < .001$).

Eight studies[49-56] had lower quality ratings because none included a control group for comparing orthopedic surgical treatment plans without 3D-IGA. Despite this limitation, all studies concluded that 3D-IGA altered orthopedic surgical planning. In each study, the orthopedic surgical plan for children with CP was recorded based on physical exam and qualitative visual assessment of walking. The children then underwent 3D-IGA, after which another orthopedic surgical plan was developed. Post-IGA plans differed from pre-IGA plans in all 8 studies (Table 3). In 6 studies, the initial referring physician differed from the physician making the post-IGA orthopedic surgical plan.[50-54,56]

Cook et al.[49] specifically assessed whether 3D-IGA altered the plan to perform or avoid orthopedic surgery. They controlled for possible inter-surgeon differences by ensuring that the referring physician and 3D-IGA physician were the same individual. The plan for orthopedic surgery or no surgery remained the same for 89% of the cases. However, 11% had a change in recommendations with 10 of 11 cases changing from an orthopedic surgical recommendation to no surgery. Therefore, this study suggests that 3D-IGA could be used to identify children who do not need orthopedic surgery.

Nine studies addressed whether specific orthopedic surgical procedures should be added or removed.[46,49-56] Surgical decisions were grouped by muscle (psoas, hip adductors, hamstrings, rectus femoris, and gastrocnemius/soleus) and bone rotation surgery (femoral derotation osteotomy, and tibial derotation osteotomy) though the naming and number of procedures varied across studies. Although the findings were not unanimous, adding 3D-IGA often led to recommendations of more psoas surgery and less hip adductor and hamstring surgery. Rectus femoris, gastrocnemius/soleus, and derotational osteotomy surgeries had more mixed recommendations. Wren et al.[46] found that recommendations for surgical lengthening of the gastrocnemius/soleus were both added (3/8, 38%) and subtracted (18/45, 40%) for different children.

In summary, conducting 3D-IGA before orthopedic surgery may change decisions about surgical procedures: individual procedures may be added, changed, or removed or plans for surgery may be withdrawn altogether.

Post-Orthopedic Surgical Outcomes: Eight studies (9 publications) aimed to identify whether adding 3D-IGA resulted in improved post-orthopedic surgical outcomes for children with CP who walk.[35,47,48,55,57-61] One RCT (2 manuscripts)[47,48] and 7 quasi-experimental studies concluded that following 3D-IGA treatment recommendations led to better post-operative outcomes.[35,55,57-61]

One RCT (2 publications)[47,48] demonstrated that gait analysis improved outcomes when its recommendations were incorporated in the treatment plan. This RCT randomly assigned children with CP scheduled for orthopedic surgery to groups that either received or did not receive a pre-operative 3D-IGA report for surgical planning. Surgeries included specific procedures, such as external femoral derotation osteotomy (FDRO)[47] or more general procedures categorized as "None," "Single level," or "Multi level."[48] For the group that received the 3D-IGA report with a recommendation for FDRO and actually had the procedure, results demonstrated that 1-year outcomes including femoral anteversion, mean hip rotation in stance, and mean foot progression angle in stance were improved.[47] For general orthopedic surgery categorization, the group that received the 3D-IGA report and for whom over half of the surgical recommendations were followed, walking outcomes improved significantly and were clinically meaningful as measured by the Gait Deviation Index (GDI) and the Gillette Functional Assessment Questionnaire.[48]

A noteworthy aspect of these publications was that although following recommendations based on 3D-IGA improved post-orthopedic surgical outcomes, low compliance rates with gait analysis recommendations were reported. For example, Wren et al.[48] reported that less than half (42%) of the 3D-IGA recommendations were followed. Another publication[47] identified that only 7 of 39 FDROs recommended by 3D-IGA were performed. Factors thought to contribute to low adherence rates with gait analysis recommendations included: differences in treatment patterns among surgeons and institutions, lack of routinely performing procedures recommend by 3D-IGA, such as a distal rectus femoris transfer, lack of experience with extensive SEMLS interventions, and child/family reluctance to alter prior plans.[48]

Seven quasi-experimental retrospective studies lacked randomization and other characteristics associated with RCTs.[35,55,57-61] These studies consistently concluded that a 3D-IGA was useful for improving post-operative outcomes. Molenaers et al.[59] reported that when 3D-IGA was included in clinical decision making, the age of the child at first orthopedic surgical procedure increased for children with CP. When 3D-IGA results were included in the decision making and recommendations were followed, there were greater improvements in post-operative physical examination measures,[58] temporal-spatial parameters,[35] and either select discrete kinematics (eg, peak minimum knee flexion in stance phase) or summary metrics of walking quality (eg, Gillette Gait Index and GDI).[57,58] Vuillermin et al.[61] demonstrated that inclusion of 3D-IGA in the clinical management of children with CP who walk altered orthopedic surgical management of equinus and significantly reduced severe crouch gait prevalence later in life.

Cost Outcomes: Three studies investigated the impact of 3D-IGA on health care costs.[50,62,63] A retrospective study of children with CP who walk investigated 3D-IGA effects on the costs of care and the number of surgeries received.[63] Results showed that children who underwent surgical procedures using 3D-IGA had more surgical procedures and initial higher costs compared with children who underwent surgeries without 3D-IGA. In contrast, a larger proportion of the children who underwent surgical procedures without 3D-IGA had more subsequent surgical episodes, more additional surgeries per person, and higher additional costs. This study supported that 3D-IGA was associated with a lower incidence of additional surgeries, overall costs, and less disruption to children's lives.[63] Single event multilevel surgeries (SEMLS) that included comprehensive 3D-IGA versus a staged surgical approach without comprehensive 3D-IGA for the treatment of multilevel walking problems resulted in lower financial costs, fewer surgical episodes, and are recommended for children with CP.[62] When surgical recommendations made by clinicians experienced in gait analysis were combined with the clinical examination, video, and 3D-IGA recommendations, the addition of gait analysis data resulted in changes in surgical recommendations in 52% of the children, with an associated reduction in surgical costs.[50]

Quality ratings for the studies supporting Action Statement I are in Supplemental Digital Content 3 available at http://links.lww.com/PPT/A522.

Research Recommendations

Future studies should investigate:

- Reasons why 3D-IGA recommendations may not be followed.
- Educational strategies to emphasize the utility of 3D-IGA for surgical decision making.
- How 3D-IGA can inform individualized orthopedic surgical approaches.
- Which combinations of discrete variables (ie, kinematic, kinetic, EMG, etc.) reliably inform particular orthopedic surgical decisions and improve clinical outcomes.
- How cost/benefit analyses associated with using 3D-IGA for surgical interventions changes with years of follow-up.

Action Statement II: Gait Deviation Analysis

B. Physical therapists, physicians, and associated clinicians should recommend 3D-IGA when a child with CP presents with gait dysfunction and there is a need to identify, quantify, and differentiate deviations among individual segments/joints and planes (sagittal, coronal, and transverse). (Evidence Quality: **II**, Rec. Strength: **Moderate**)

Aggregate Evidence Quality

Level II based on 129 high quality retrospective studies with consistent results.

Benefits

3D-IGA clarifies gait deviations by providing independent complementary kinematic and kinetic data that cannot be obtained from clinical examination alone.

3D-IGA identifies specific gait patterns for multiple segments/joints and planes (sagittal, coronal, and transverse) that explain atypical walking variability and differentiate among key determinants.

3D-IGA may assist with differential diagnosis of children with CP from children with other medical conditions who have similar gait patterns.

Risk, Harm, Cost

Conducting 3D-IGA can be expensive, and third-party coverage varies.

- Access to 3D-IGA labs may be limited in some geographic areas.

Families and children may need to devote substantial time and effort for travel, to attend 3D-IGA sessions, to wait for data processing and evaluations, and to attend additional appointments that may delay implementation of interventions.

Benefit-Harm Assessment

Preponderance of benefit

Value Judgments

None

Intentional Vagueness

The CPG does not endorse any brand or constellation of equipment, modeling, protocol, or evaluative processes for 3D-IGA. Although 3D-IGA is not typically a diagnostic tool, 3D-IGA can distinguish children with other disorders from children with CP and support appropriate diagnostic referrals and/or lab-based testing (such as genetic testing to exclude CP diagnosis).

Role of Child/Family Preferences

Families should have a basic understanding of 3D-IGA processes to inform their decision making and help explain the purpose and testing process to their child. Children and families should participate in shared decision making with their clinicians regarding the outcomes of 3D-IGA to establish realistic goals and expectations.

Exclusions

Children with CP who do not walk (GMFCS Levels IV–V), children who require gait trainers to complete 3D-IGA, children who cannot follow simple directions, or children with cognitive or behavioral limitations that would prevent completion of gait analyses may not be appropriate for referral. If a child does not have goals or a prognosis to improve walking, 3D-IGA should not be recommended.

Quality Improvement

Information from 3D-IGA about deviations among individual segments/joints and planes (sagittal, coronal, and transverse) enhances evaluation of gait dysfunction and may improve child and service outcomes.

Implementation and Audit

Share the 3D-IGA CPG with PT referral sources to increase action statement awareness.

Develop a list of 3D-IGA laboratories in the geographic area to expedite referrals.

Develop consumer friendly supplements for parents and children about 3D-IGA and how it may assist in development of the plan of care.

Audit how often segmental and planar information from 3D-IGA helps to explain atypical gait patterns.

Audit how frequently 3D-IGA is used for differential diagnosis.

Supporting Evidence and Clinical Interpretation

One hundred twenty-nine studies were identified that address whether and how 3D-IGA enhances the examination and evaluation of gait dysfunction among children with CP. Most were retrospective investigations of child registries, representing at least 5 years of data from well-established gait labs that used standardized measurement protocols and reliable marker placement methods, established kinematic models and calculations of joint kinetics, and experienced interdisciplinary teams who worked with children and families, interpreted the data, and developed clinical recommendations based on the results.

An abundance of historical and recent literature describes the precision of 3D-IGA for quantifying specific segments/joints and planes (sagittal, coronal, and transverse) contributing to complex atypical gait patterns. Atypical gait patterns associated with CP can involve isolated deviation(s) at a particular joint/segment in 1 plane of motion (ie, ankle equinus) or have multi-segment/joint and multi-planar (sagittal, coronal, and transverse) involvement (ie, crouch with rotational malalignment).[26,64-81] 3D-IGA data can characterize, quantify, and identify factors affecting the prevalence of these patterns among children with CP who walk.

Thirty-three studies demonstrate that 3D-IGA provides body structure and function information that is unique and complementary to clinical examinations and that may differentiate key determinates of atypical gait patterns. Among numerous clinical examination and 3D-IGA measures, few resulted in strong correlations,[29,82-98] suggesting that clinical examinations and 3D-IGA data quantify different aspects of a child's presentation. Very few specific clinical examination measures correlated with gait deviations, eg, mid-point of hip rotation with dynamic hip rotation, $r = .57$.[84] Most routine clinical examination measures either demonstrated weak relationships or did not correlate with dynamic gait measures.[85,97,99-113]

Seven studies show that 3D-IGA provides unique quantitative data on deviations of segments/joints and planes (sagittal, coronal, and transverse) in characteristic gait patterns. For a chief complaint of toe walking, 3D-IGA identified and quantified individual contributions from the ankle (equinus), knee (pseudo-equinus), or both.[31,71] For a chief complaint of intoeing, 3D-IGA identified and quantified combined contributions of the trunk, hip, knee, ankle, and/or foot to overall foot progression angle.[29,30,32] For scissoring gait, 3D-IGA could distinguish between the coronal and combined sagittal-transverse planar deviations.[79,81]

Characterization and quantification of atypical gait patterns among children with CP have been conducted in 30 studies using both consensus and data-driven modeling strategies. Seminal articles described gait patterns of children with bilateral and unilateral involvement based on expert consensus.[26,27,114-118] Data-driven models have identified unique kinematic deviations associated with torsional malalignment (femoral and/or tibial increased torsion), as well as atypical patterns at the knee and foot.[29,30,32,65,77,119-130] Numerous models used 3D-IGA to quantify nuances of those patterns and their relationship(s) to other gait deviations at the trunk, pelvis, hip, knee, foot and ankle, and even the upper extremities.[69,72,73,75,76,116,131-149] Other models evaluated the effects of growth and development on gait deviations and gait patterns and how they changed during different functional activities, eg, running.[150-153] The ultimate goal of this line of research was to identify and better understand these

unique gait patterns and deviations among children with CP to inform intervention planning.

The prevalence of common atypical gait patterns involving multiple segments/joints and/or planes (sagittal, coronal, and transverse) have been reliably characterized and described using combinations of kinematic variables.[117,121,130,154-158] Additionally, child-specific factors including age, sex, anatomical distribution of involvement, ie, unilateral and bilateral, and measures of function, eg, GMFCS level, have been shown to be associated with the prevalence of particular segment/joint and plane (sagittal, coronal, and transverse) gait deviations.[32,85,135,154,155,159-166]

Finally, 3D-IGA has identified unique characteristics that differentiate between 2 pediatric populations that walk with similar gait deviations and atypical patterns, including children with CP versus children with idiopathic toe walking,[31,124,167] and spastic versus dyskinetic[168] or hereditary spastic paraparesis.[169-173] While 3D-IGA can identify unique characteristics in different pediatric populations, it does not exclusively provide a differential diagnosis.

Research Recommendations

Research is needed to investigate:

- The contributions of additional 3D-IGA elements including trunk, upper extremity, segmental foot, and ankle kinematics;
- The role of supplemental IGA data including EMG when characterizing gait dysfunction;
- Pattern characterization using data from the entire gait cycle as opposed to discrete kinematic variables;
- Methods for automating analytic processes to identify associations among gait deviations, atypical gait patterns, and clinical measures;
- Atypical gait pattern changes across time and among individuals with different topographical classifications of CP.

Action Statement III: 3D-IGA to Evaluate Biomechanical Outcomes

B. When PTs, physicians, and associated clinicians need to evaluate biomechanical aspects of walking related to an intervention for children with CP, they should recommend baseline and post-intervention 3D-IGA. (Evidence Quality: **III,** Rec. Strength: **Weak upgraded to Moderate**)

Aggregate Evidence Quality and Strength

Level III: This action statement was upgraded based on descriptive analysis of many studies (n = 460), the majority of which effectively used 3D-IGA as the primary tool to measure intervention outcomes.

Benefits

3D-IGA can be used to quantitatively assess gait deviations, including changes in gait kinematics, kinetics, and muscle activations.

3D-IGA can be used to evaluate the effectiveness of interventions with more accuracy and precision than many clinical tools at the body structure and function level and can be used to determine the need for future operative and non-operative interventions.

3D-IGA can be used to track longitudinal changes in gait patterns over the short and long term with more reliability and precision than standardized clinical tools.

Risks, Harms, Cost

3D-IGA can be expensive/lead to additional costs for families and may not be covered by third party payers.

Access to 3D-IGA labs may be limited in some geographic areas.

Families and children may need to devote substantial time and effort for travel, to attend 3D-IGA session, to wait for data processing and evaluation, and to attend additional appointments.

Benefit-Harm Assessment

Preponderance of benefit

Value Judgments

None

Intentional Vagueness

This guidance statement does not identify specific interventions, nor whether they are surgical or non-surgical. While 3D-IGA recommendations are designed to measure effectiveness of interventions, intervention planning, and procedures are determined by many factors beyond the 3D-IGA study, such as child goals, surgical techniques, and rehabilitation approaches. This recommendation does not imply that all children with CP who receive interventions should have a baseline and post-intervention 3D-IGA; rather, there should be a specific child/family or clinical concern about walking that could be answered by 3D-IGA. The CPG does not endorse any brand or constellation of equipment, modeling, protocol, or evaluative processes for 3D-IGA.

Role of Child/Family Preferences

Families should have a basic understanding of 3D-IGA processes to inform their decision making and help explain the purpose and testing process to their child. Children and families should participate in shared decision making with their clinicians regarding the outcome of 3D-IGA to establish realistic goals and expectations. 3D-IGA services for an individual child should be based on a child's current status, prognosis, rehabilitation goals, and family resources.

Exclusions

Children with CP who do not walk (GMFCS Levels IV–V), children who require gait trainers to complete 3D-IGA, children

who cannot follow simple directions due to age, or children with cognitive or behavioral limitations that would prevent completion of gait analyses may not be appropriate for referral. If a child does not have goals or a prognosis to improve walking, 3D-IGA should not be used to assess changes in walking.

Quality Improvement

3D-IGA can be used to evaluate short-term and long-term changes resulting from different interventions. Data can be used to validate clinical assessments, measure global and specific gait pattern changes, and generate new knowledge about examinations and interventions used with children with CP who walk.

Implementation and Audit

Educate PTs and associated clinicians about how the deviations among segments/joints and planes (sagittal, coronal, and transverse) identified through 3D-IGA can be used to assess the value of an intervention designed to improve walking.

Audit which 3D-IGA measures were found to be most useful for PTs in quantifying intervention outcomes.

Audit which gait deviations and associated interventions led clinicians to use 3D-IGA to track outcomes.

Supporting Evidence and Clinical Interpretation

A total of 460 studies used 3D-IGA to evaluate the effects of an intervention on gait deviations. The studies used a wide array of quantitative outcome measures derived from kinematic, kinetic, or EMG data. Many also used clinical measures related to walking or child presentation. The focus here is on whether 3D-IGA provided useful tools to gauge the impact of interventions, not on whether the interventions were effective for managing gait dysfunction. Of the 460 studies reviewed, 407 (88%) found a significant difference in at least 1 3D-IGA outcome measure, 19 (4%) found no significant differences, and 34 (7%) provided only descriptive data. The large number of publications showing statistically significant findings supports that 3D-IGA outcome measures were useful for assessing intervention effects.

All included studies met our definition of 3D-IGA and many used force plates (n = 151, 33%) or EMG (n = 56, 12%). The studies assessed a range of interventions (Table 4) including orthopedic surgeries (219, 48%), PT, and exercise interventions (n = 67, 15%), orthotics (n = 63, 14%), or Botulinum toxin A (n = 46, 10%). Fewer studies tested the effectiveness of other interventions, such as selective dorsal rhizotomy surgery, electrical stimulation, robotics, virtual reality, intrathecal baclofen, casting, or transcranial magnetic stimulation (Table 4).

While this analysis provides some guidance as to the types of interventions that can be assessed using 3D-IGA, it does not address the merits of specific variables or analyses performed. There are numerous ways to combine kinematic, kinetic, and EMG data to yield potentially useful information about gait dysfunction. It is not within this CPG's scope to identify or assess the large variety of measures derived from 3D-IGA; readers are directed to Cimolin and Galli[174] for further information. It is important for clinicians and researchers to recognize the broad categories of 3D-IGA outcome measures, includin: standardized summary scores, eg, the Gait Deviation Index; discrete measures of gait deviations (eg, peak knee flexion during swing); full time series analysis; and uniquely derived models that combine specific gait variables to address the aims of a particular study. The standardized summary scores define normative scores for children with CP and other disorders. They have been validated extensively and may be most relevant for clinicians and families.[175-177] More discrete 3D-IGA outcome measures quantify gait deviations critical to a particular gait dysfunction, eg, the extent of knee motion during swing phase is instructive for children with stiff knee gait.[178] Other uses of 3D-IGA data, such as for derivation of unique multivariable models or complex approaches to combining specific features of walking, may be more suitable for research purposes, but can be clinically applied in particular circumstances.

TABLE 4
Frequency of Interventions Assessed Using 3D-IGA

Intervention	Number of studies and percentage	Kinematics	Kinetics	EMG
Surgeries (not including selective dorsal rhizotomy)	219 (48%)	219	70	21
Physical therapy and exercise	67 (15%)	67	11	7
Orthotics	63 (14%)	63	28	5
Botulinum toxin A	46 (10%)	46	16	9
Selective dorsal rhizotomy	24 (5%)	24	8	7
Robotics	18 (4%)	18	6	1
Electrical or transcranial magnetic stimulation	18 (4%)	18	5	4
Virtual reality	6 (1%)	6	3	1
Casting	4 (1%)	4	1	0
Intrathecal baclofen	2 (1%)	2	0	0

Research Recommendations

Studies are needed to:

- Outline which 3D-IGA measures are most important when evaluating the effectiveness of surgical, medical, and rehabilitation interventions to enhance examination precision.
- Determine if and when standardized collection of quantitative summary measures from 3D-IGA at regular intervals would improve clinical oversight, provide for timely interventions to prevent future or more severe complications and prognoses of the recurrence of gait dysfunction.
- Investigate methods to make 3D-IGA more accessible.

Action Statement IV: Non-Surgical Interventions

C. PTs, physicians, and associated clinicians may recommend 3D-IGA to inform non-surgical interventions for children with CP with gait dysfunction whose progress from rehabilitative interventions and conservative management has plateaued or shown substantial deterioration. (Evidence Quality: **III**; Rec. Strength: **Weak)**

Aggregate Evidence Quality

Level III based on 2 high quality studies with methods that precluded direct application to the question of interest.

Benefits

Individually tailored, interdisciplinary rehabilitation approaches informed by 3D-IGA may improve gross motor function more efficiently than when compared with usual care.

3D-IGA may guide selection of non-surgical interventions by clarifying relationships amongst biomechanical impairments associated with the child's gait dysfunction.

3D-IGA may facilitate communication amongst the interdisciplinary team of health care providers, the child, and family.

3D-IGA may help clinicians to avoid ineffective interventions that could be costly and delay effective treatment.

No adverse events were reported secondary to participating in 3D-IGA.

Risk, Harm, Cost

Conducting 3D-IGA can be expensive and third-party coverage varies.

Access to 3D-IGA labs may be limited in some geographic areas.

Families and children may need to devote substantial time and effort for travel, to attend 3D-IGA sessions, to wait for data processing and evaluations, to attend additional appointments that may delay treatment implementation.

Benefit-Harm Assessment

Equivalent

Value Judgments

None

Intentional Vagueness

The CPG does not endorse any brand or constellation of equipment, modeling, protocol, or evaluative processes for 3D-IGA. While 3D-IGA recommendations are designed to aid clinical decision making, interventions are determined based on many factors in addition to data from a 3D-IGA study, such as the child's specific presentation, the therapeutic interventions considered, any adjuvant care, and the goals and resources of the child and family.

Role of Child/Family Preferences

Families should have a basic understanding of 3D-IGA processes to inform their decision making and help explain the purpose and testing process to their child. Children and families should participate in shared decision making with their clinicians regarding the use of 3D-IGA to inform future plans of care and to establish realistic goals and expectations. Ultimately, it is up to the family and treating clinicians to determine if 3D-IGA is feasible and how to integrate recommendations derived from 3D-IGA.

Exclusions

Children with CP who do not walk (GMFCS Levels IV–V), children who require gait trainers to complete 3D-IGA, children who cannot follow simple directions due to age, or children with cognitive or behavioral limitations that would prevent completion of gait analyses may not be appropriate for referral. If a child does not have goals or a prognosis to improve walking, 3D-IGA should not be used.

Quality Improvement

Integration of 3D-IGA results with rehabilitation plans may inform gait interventions for children with CP who walk.

Implementation and Audit

Share the 3D-IGA CPG with colleagues and other health care professionals in the geographic area to increase awareness of the action statements.

Develop educational materials for PTs about how the kinematic and kinetic information generated by 3D-IGA can assist with decision making about non-surgical interventions.

Clinicians may require education on the benefits and limitations of 3D-IGA for children who have plateaued in their walking skills.

Provide parent friendly materials to educate families about the benefits, costs, and limitations of 3D-IGA for children needing non-surgical care.

Assist families to identify appropriate 3D-IGA laboratories that can assess children for non-surgical interventions.

Audit the frequency of 3D-IGA use for non-surgical intervention decision making.

Supporting Evidence and Clinical Interpretation

Two studies reported across 4 articles compared non-surgical interventions influenced by 3D-IGA to similar interventions without using 3D-IGA.[179-182] Neither study was designed to primarily address whether inclusion of 3D-IGA affects non-surgical outcomes, and both made methodological choices that obscured this question. While both studies were RCTs, they

explored a very small subset of potential non-surgical interventions that might benefit from using 3D-IGA to individualize interventions. The strength of the current action statement was based on expert opinion and these studies[179-182] that indirectly support individualized, goal-directed, and task-specific interventions to improve measures of activity in children with CP.

Franki et al.[180] conducted a randomized pilot study with a sample of 10 children with bilateral spastic CP. The aim was to compare the effects of an individualized PT treatment plan informed by 3D-IGA to a general PT treatment plan that did not use the 3D-IGA pretest results. Outcome measures included Gross Motor Function Measure (GMFM-88) scores, time and distance parameters, gait profile score, movement analysis profiles, and goal attainment scaling.[180] No significant differences in the GMFM-88 were found, and the individualized treatment group had small benefits in 2 of 13 dependent variables. Thus, while movement analysis profile scores for the pelvis in the transverse plane and step length significantly improved in the individualized therapy group, movement analysis profile scores did not change for other joints and planes, ie, ankle, knee, hip, and pelvis, other time and distance parameters, including the gait profile score and goal attainment scaling. A post-hoc analysis determined that future studies would require a sample size of 72-90 participants, emphasizing the preliminary nature of their findings. The second report of this same trial[179] included 40 children, but allowed for some children to be treated with botulinum toxin independent of this trial, and some children participated in multiple groups within the trial. These confounding factors further obscured the role of 3D-IGA, making the results difficult to interpret for this question. Very similar types of activities were included in both the general and individualized groups. The primary difference was the organization of interventions in the documented plan of care. For the general group, treatment activities were organized based on themes including strengthening, selectivity and mobility, and functional activities. For the individualized group, treatment strategies were organized based on identified goal areas from the 3D-IGA, but very similar activities were employed to address those goal-associated problems. As a result, the interventions effectively did not differ, lowering the perceived evidence quality and support for the action statement.

Rasmussen et al.[182] included 60 participants, 30 per group, to compare interventions based on 3D-IGA versus usual care on walking quality using the GDI and patient-reported outcomes of function, disability, and health-related quality of life. No between-group effects were found; of the minimal within-group effects reported, many did not meet or exceed minimally clinically important differences. Many children did not follow the prescribed interventions; only 36% complied with the prescribed spasticity management, and none complied with recommendations for surgery, thus compromising the study. Fonvig et al.[181] evaluated data from the same study to investigate the effects of individualized, interdisciplinary interventions based on 3D-IGA versus usual care on 5 domains of the Measure of Process of Care (MPOC-20). This evaluation was a "secondary analysis of tertiary data" and did not directly measure the outcome of gait dysfunction. There were no between-group or within-group effects for either group on the MPOC-20 at the 26-week or 52-week time points. This study did find that children who had 3D-IGA included in treatment planning showed small but significant gains in GMFM scores compared with those receiving usual care; however, inconsistent treatment compliance and factors beyond the inclusion of 3D-IGA may have affected outcomes.

Quality ratings for the studies supporting Action Statement IV can be found in the Supplemental Digital Content 3 available at http://links.lww.com/PPT/A522.

Research Recommendations

High-quality RCTs including children with CP who walk are needed to:

- Compare the use or absence of 3D-IGA with non-surgical interventions, including rehabilitation, orthotics, and medications, to improve walking quality.
- Identify sub-groups of children with CP who would benefit from particular non-surgical interventions.

Action Statement V: Instrumented Gait Analysis Equipment

P. When 3D-IGA is recommended for children to comprehensively assess gait patterns, PTs, physicians, and associated clinicians should recommend gait labs that can collect 3-dimensional kinematic, kinetic, and EMG data. (Evidence Quality: **V**, Rec. Strength: **Best Practice)**

Aggregate Evidence Quality

Level V based on accreditation guidelines established by the Commission for Motion Laboratory Accreditation (CMLA) and expert clinical consensus of the GDG.

Benefits

3D-IGA performed with the recommended set of equipment and instruments has the capacity to provide a comprehensive analysis of walking including detailed information on spatiotemporal measures, kinematics, kinetics, and EMG.

Multiple streams of integrated 3D-IGA data may identify subtle underlying impairments and guide clinical decision making.

Risk, Harm, Cost

3D-IGA can be expensive for families and may not be covered by third party payers.

Laboratories with the recommended set of equipment and instruments may be farther away or less accessible to the child and family.

3D-IGA laboratories without the recommended set of equipment and instruments may not be able to provide comprehensive and accurate data analysis and results.

Benefit-Harm Assessment

Benefits outweigh the risks

Value Judgments

Motion/gait analysis instruments and equipment vary in type and quality. Instruments that only measure spatiotemporal measures or 2-Dimensional movements may not provide the necessary and/or appropriate data to fully support surgical and non-surgical clinical decisions in the management of gait dysfunction in children with CP.

Intentional Vagueness

The CPG does not endorse any brand or constellation of equipment, modeling, protocol, or evaluative processes for 3D-IGA. No specific research is currently available on the minimum set of instruments/equipment necessary for 3D-IGA for children with CP. This action statement is based on reviewing the following studies and documents: a scoping review on gait analysis for children with CP,[2] needs assessment,[1] recommendations by GCMAS,[183] CMLA Accreditation criteria,[184] and a published report by the Italian Society of Clinical Movement Analysis on Gait Laboratories.[185]

Role of Child/Family Preferences

The choice of a gait lab should be a shared decision with the family and referring health care professional.

Exclusions

Children with CP who do not walk (GMFCS Levels IV–V), children who require gait trainers to complete 3D-IGA, children who cannot follow simple directions due to age, or children with cognitive or behavioral limitations that would prevent completion of gait analyses may not be appropriate for referral.

Quality Improvement

Laboratories that provide 3D-IGA can provide integrated comprehensive gait reports to inform clinical decisions for children with CP who have gait dysfunctions.

Comprehensive and precise data on 3D-kinematics, kinetics, and EMG may facilitate accurate documentation of gait dysfunctions in children with CP.

Implementation and Audit

- Develop and provide a list of 3D-IGA labs in the geographic area, the instruments and equipment available at those facilities, and documented quality assurance programs of lab staff and equipment for PTs, parents and referral sources. If a lab has CMLA accreditation, the lab will have appropriate instruments and equipment.
- Audit reports from commonly recommended labs for the equipment available and services provided.

Supporting Evidence and Clinical Interpretation

Decisions about which instruments/equipment to use when assessing walking of children with CP clearly depend upon the assessment goals. This action statement focuses on the instruments/equipment needed to perform a comprehensive assessment of specific gait deviations among segments/joints and planes (sagittal, coronal, and transverse) that explain variability and differentiate between key determinants of characteristic atypical gait patterns.

3D motion capture alone can provide useful kinematic information. However, additional capabilities (3D kinematics along with kinetics and muscle activity) must be available for a 3D-IGA laboratory to meet accreditation criteria consistent with the CMLA.[184] These guidelines recommend an integrated system including:

- 3D motion capture covering the entire kinematic chain (usually provided by a multi-component optical system);
- A validated biomechanical model and marker set;
- One or more force platforms (kinetics);
- EMG of selected muscles or muscle groups (muscle activity);
- Software for data processing.

EMG and force platforms may not be necessary in every instance but may be especially important when considering select surgical interventions.

Additional tools may be added to this minimum set for specialized purposes and may include plantar pressure assessment, foot-worn pressure sensors, ventilatory gas analysis (O_2 consumption), and a multi-segment foot model as an adjunct to the standard model. Spatiotemporal parameters, kinematics, kinetics, and neuromuscular behavior of specific muscles or muscle groups can be obtained through other measurement tools and approaches when used in isolation. These include standardized rating scales, digital video recording, kinematic analysis based on 2D videos, temporal-spatial measurement of footfalls using pressure sensors, instrumented gait mats, body worn sensors to provide kinematic and/or kinetic information of individual body segments, isolated use of force platforms or EMG, and mobile device applications that integrate and interpret 1 or more of the listed technologies. Isolated tools may be more clinically accessible, and less costly, less cumbersome and time consuming to apply, and require less technical support. The data from these isolated tools can help to quantify selected aspects of walking but cannot provide the integrated comprehensive analysis of 3D movement across the kinetic chain, and they may not have the accuracy and precision of 3D-IGA. 3D-IGA provides the comprehensive and cohesive assessment of spatiotemporal, kinematic, kinetic, and neuromuscular activity of EMG needed to fully assess and identify specific deviations among segments/joints and planes (sagittal, coronal, and transverse) that explain key determinants of atypical gait patterns.

Research Recommendations

Research is needed to:

- Identify the minimum set of integrated instruments and equipment necessary for gait analysis in children with CP under different clinical situations.
- Clarify when instruments and equipment associated with 3D-IGA, such as kinetics, EMG, foot pressure sensors, and oxygen consumption are critical to provide comprehensive and efficient evaluation of gait patterns.
- Evaluate the clinical benefits of new technologies that advance existing capabilities of 3D-IGA.

Action Statement VI: Interdisciplinary Team Approach

P. When 3D-IGA is recommended for children to assess gait patterns, PTs, physicians, and associated clinicians should recommend a 3D-IGA laboratory that has an interdisciplinary team approach. (Evidence Quality: **V**, Rec. Strength: **Best Practice**)

Aggregate Evidence Quality

Level V based on expert clinical consensus of the GDG and CMLA accreditation guidelines

Benefits

An interdisciplinary lab team can assemble multiple perspectives from medical, surgical, biomechanical, engineering, and rehabilitation providers, including PTs, on the relationship among biomechanical impairments associated with a child's gait dysfunction, and potential clinical interventions, such as physical rehabilitation, assistive mobility devices/orthotics, and medical/surgical procedures, to address spasticity or orthopedic conditions that limit function or independence.

Risk, Harm, Cost

Lack of an appropriately trained and competent interdisciplinary team may affect the quality of 3D-IGA interpretation.

Lack of an appropriately trained and competent interdisciplinary team may result in decisions based on 1 perspective or the interest of 1 specialist.

Laboratories with an appropriate interdisciplinary team may be farther away or less accessible to the child and family.

Benefit-Harm Assessment

Preponderance of benefit

Value Judgments

The GDG recognizes its bias toward the use of an interdisciplinary team approach over a single professional approach based on prior experience with both service models.

Intentional Vagueness

The specific training and composition of the ideal interdisciplinary team has not been studied or determined.

Role of Child/Family Preferences

Children and families should participate in shared decision making with their clinicians to identify gait labs with interdisciplinary teams that address their walking goals.

Exclusions

Children with CP who do not walk (GMFCS Levels IV–V), children who require gait trainers to complete 3D-IGA, children who cannot follow simple directions due to age, or children with cognitive or behavioral limitations that would prevent completion of gait analyses may not be appropriate for referral.

Quality Improvement

Using interdisciplinary teams to interpret 3D-IGA outcomes may reduce iatrogenic errors, improve child experience and quality of care, and reduce costs.

Implementation and Audit

- Develop and provide a list of 3D-IGA labs in the geographic area with interdisciplinary teams and documented quality assurance programs of lab staff and equipment as a resource for children and families. If a lab has CMLA accreditation, the lab will have an interdisciplinary team.
- Audit the comparative quality of reports from gait labs with and without interdisciplinary teams.

Supporting Evidence and Clinical Interpretation

No studies have specifically examined combinations of professionals providing 3D-IGA services for children with CP though a recent needs assessment found that PTs, engineers, kinesiologists, physicians and surgeons, and orthotists commonly work in 3D-IGA laboratories.[1] There is evidence of the benefit of multidisciplinary decision making, in general, in health care.[186]

Benedetti et al.[185] reported on the required training and experience of professionals working in a laboratory performing 3D-IGA and recommended the following: (1) knowledge of biomechanics and neurophysiology of human movement, (2) knowledge of advantages and limitations in the different techniques adopted for data recording and interpretation, (3) adequate skills in the practical application of the assessment, and (4) adequate training for data processing and representation. Based on the above criteria, the professional profiles for a 3D-IGA laboratory might include: (a) physicians who specialize in areas relevant to the study of movement and movement disorders,

ie, orthopedists, neurologists, neurosurgeons, physiatrists, or sports medicine physicians, (b) health care professionals with specific experience in human motion and movement disorders, ie, PTs, psychomotor developmental therapists, occupational therapists, and orthotists, (c) biomedical engineers with specific expertise on motion analysis and basic instrumentation used in 3D-IGA, and (d) human movement scientists or kinesiologists with health care emphasis. However, a particular degree or credential does not guarantee the individual has the entire skill set needed. Interdisciplinary team members need comprehensive education in 3D-IGA as well as the associated background knowledge and practice to ensure valid interpretation. Most 3D-IGA professionals learn these skills through ancillary education and practice experience.

Accreditation by CMLA[184] requires that personnel involved in motion/gait analysis laboratory perform activities that are within their scope of practice. CMLA requires that data interpretation teams and clinical recommendation teams include at least 1 licensed clinician with demonstrated knowledge and expertise for treatment of conditions present in the population being served.

There is a consensus among 3D-IGA experts that an interdisciplinary team should be involved in the 3D-IGA laboratory serving children with CP,[183] including some combination of PTs, orthopedists, neurologists, physiatrists, engineers, biomechanists, kinesiologists, orthotists, and clinical researchers.

Research Recommendations

- Studies are needed to determine the most effective combination of personnel for 3D-IGA interdisciplinary teams and methods to indicate competence.

Action Statement VII: Comprehensive Reports

P. When 3D-IGA is recommended for children to assess gait patterns, PTs, physicians, and associated clinicians should recommend 3D-IGA laboratories that provide comprehensive, timely, and interdisciplinary reports including: (a) referral source and reason for referral; (b) diagnosis including Gross Motor Function Classification System (GMFCS) level; (c) primary concerns or goals of the child, family, and health care professionals including PTs; (d) pertinent past medical history; (e) current orthoses and adaptive equipment; (f) findings of physical exam; (g) documentation of 3D-IGA results; (h) limitations in conducting the assessment and or technical issues; (i) interpretation of findings by licensed clinician(s) with 3D-IGA expertise (eg, MD and/or PT); and (j) suggestions for interventions by licensed clinician(s) with advanced training in 3D-IGA.

(Evidence Quality: **V**, Rec. Strength: **Best Practice**)

Aggregate Evidence Quality:

Level V based on expert clinical consensus of the GDG and accreditation criteria established by the CMLA

Benefits

- Comprehensive reports enable health care providers to understand the complex relationships between the gait findings (kinematic, kinetics, and EMG) and the physical exam (eg, strength or contractures) associated with the child's gait pattern.
- Comprehensive reports provide quantitative data to support contextual information from the clinical presentation and examination that guide potential clinical interventions (eg, physical rehabilitation, prescription of assistive mobility devices and orthotics, medical treatments to address spasticity, and neurologic and orthopedic surgeries).
- Comprehensive reports facilitate communication amongst the interdisciplinary team members and the child and family.

Risk, Harm, Cost

- Inaccurate or incomplete information about 3D-IGA, along with misinterpretation of 3D-IGA results or recommendations, could negatively impact implementation of appropriate interventions for the child with CP.
- Laboratories that provide comprehensive reports may be further away or less accessible to the child and family.

Benefit-Harm Assessment

Preponderance of benefit

Value Judgements

None

Intentional Vagueness

- No studies have established documentation standards for 3D-IGA reports for children with CP.
- No specific format or ordering of elements of a 3D-IGA report are provided. For example, the list of suggestions for interventions could be presented first or last as an overall summary. In addition, this list of suggestions for interventions could be prioritized by order of importance.

Role of Child/Family Preferences

Children and their families should share the results and interpretation of the 3D-IGA with all individuals involved in the care and management of their child.

Exclusions

Children with CP who do not walk (GMFCS Levels IV–V), children who require gait trainers to complete 3D-IGA, children who cannot follow simple directions due to age, or children with

cognitive or behavioral limitations that would prevent completion of gait analyses may not be appropriate for referral.

Quality Improvement

Standardized reporting of 3D-IGA results across gait labs will improve communication among clinicians, children, and their families.

Standardized reporting across 3D-IGA labs may support quality improvement and quality assurance efforts within a department.

Implementation and Audit

- Develop and provide a list of 3D-IGA labs in the geographic area that provide comprehensive, timely, and interdisciplinary reports. If a lab has CMLA accreditation, the lab will provide a comprehensive report.
- PTs should audit the time between completion of the 3D-IGA session and reporting of results to referral sources and/or children.
- Clinicians may a require education/training on reading and interpreting results included in a 3D-IGA report.
- Gait labs can develop standard reporting templates with the recommended headings.

Supporting Evidence and Clinical Interpretation

While no studies have identified documentation standards, several sources provide industry guidance. The CMLA Application Review Criteria specifically identifies the information that should be included in a 3D-IGA report to support accreditation of a gait analysis laboratory.[184] The APTA provides general guidance on documentation of examination and evaluation results within the framework of the Patient Management Model.[187] A position paper from the Italian Society of Clinical Movement Analysis[185] on 3D-IGA in clinical practice focuses on general requirements, personnel, equipment, and methods, and reinforces the need for clinician expertise in 3D-IGA to analyze and interpret the results in order to provide the best information to favorably affect functional outcomes. These published international accreditation and industry guidelines provide more detailed items to include in a 3D-IGA report and are consistent with best clinical practices. Hence, the following detailed list is recommended in a 3D-IGA report[184]:

- Child demographics;
- Referral source, reason for referral;
- Diagnosis including GMFCS level[16,17];
- Current concerns of child, family, therapists;
- Pertinent medical history, past surgical/spasticity management interventions;
- Recent therapy received including intervention type, frequency, and duration;
- Current orthotic, adaptive devices in use;
- Results of clinical examination including:
  - Passive/Active range of motion,
  - Muscle testing; manual/mechanical/functional strength, spasticity measures, and selective motor control of relevant muscle groups.

- Complete data set including:
- Kinematic Data
  - Test conditions: barefoot, shoes, walking devices, with or without orthotics,
  - Type of data presented: consistency of multiple strides, representative trial, average of multiple trials,
  - Clear labeling of plots, ie, right/left axis,[184]
  - Typically developing data included on plots and clearly identified,
  - Temporal–spatial data.

- Kinetic Data
  - Test conditions, type of data presented (eg, internal or external moments), clear plots, data from typical walking,
  - Forces, moments and/or powers normalized to bodyweight.

- EMG data
  - Test conditions, type of data presented, clear plots, data from typical walking,
  - Processing methods (ie, enveloped, root mean square),
  - Muscles clearly identified.

- Optional information
  - Photos (eg, static standing, foot structure, internal/external hip rotation).

The GDG recommends that a comprehensive clinical report integrate the perspectives of the child and family regarding goals the perspectives of the interdisciplinary team, information from a comprehensive clinical examination and the 3D-IGA, and recent research. It should:

- Organize the report by anatomic region or problem list;
- Identify clinically important deviations;
- Identify possible interventions;
- Identify professionals who provided input.

Research Recommendations

- Studies are needed to develop consensus on a standardized 3D-IGA report format for professionals, parents, and children involved in the care and management of children with CP.

CPG SUMMARY/CONCLUSIONS

A review of the literature resulted in 7 graded action statements with varying levels of obligation that describe the role of 3D-IGA in the clinical management of children with CP who walk and present with gait dysfunction. These statements address 3D-IGA's utility to inform orthopedic surgical and

non-surgical interventions, to identify/quantify gait deviations among segments/joints and planes (sagittal, coronal, and transverse), and to evaluate the effectiveness of an intervention. Action statements also provide guidance to clinicians and families when considering preferred characteristics of appropriate 3D-IGA laboratories including instrumentation/equipment, staffing, and reporting practices.

Plan for Revision

This guideline was published in 2024 and will be updated or reaffirmed in 2029, or sooner if new evidence significantly impacts a recommendation; the Chair of the GDG will initiate this process.

Glossary (Supplemental Digital Content 4 available at http://links.lww.com/PPT/A523).

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