Instrumented Gait Analysis in the Care of Children with Cerebral Palsy

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Abstract: Analysis of a child's gait is an important aspect of a pediatric orthopaedic evaluation. Children with cerebral palsy often have significant gait impairments that negatively impact their ambulation, activity in society, and their quality of life. Instrumented gait analysis, with motion capture, can provide significant data to help the surgeon better understand specific pathophysiology and to plan surgical correction. Modern instrumented gait analysis is comprised of kinematics, kinetics, electromyography, pedobarography, and metabolic assessment. Newer technology allows for wearable measurement devices in the community to provide information about environmental activity, such as step counts, that augment traditional gait analysis. Literature suggests that the use of instrumented gait analysis can be effective in the treatment and care of children with cerebral palsy. Following surgical recommendations from gait analysis can lead to changes in surgical plans derived from physical exam alone, overall fewer surgical procedures, and possibly improved outcomes.

Key Concepts:

- Gait analysis is an important aspect of a thorough pediatric orthopaedic evaluation.
- Children with cerebral palsy have complex gait impairments that need a systematic approach to completely understand the pathophysiology.
- Instrumented gait analysis provides significantly additional data to help provide improved understanding of complex gait.
- Modern gait laboratories typically include kinematics, kinetics, electromyography, pedobarography, and metabolic assessment.
- Literature on the efficacy of instrumented gait analysis is limited, but most reports show improved outcomes and potentially more efficient care if surgical plans recommended by gait analysis are followed.

Introduction

A complete physical examination of any ambulatory child typically includes a thorough gait examination. Knowledge of the phases of gait,[1] and the prerequisites for normal gait should be in the knowledge base of all pediatric orthopaedic surgeons.[2] Children and adolescents with cerebral palsy (CP) often have gait impairments that negatively impact their function, activities, and participation in society.[3] A thorough, problem-focused gait exam in children with neuromuscular disabilities is essential.[4] This should start with an observational gait examination (OGA) in the office, and many resources are available in the literature to assist with performing a high-quality observational gait exam.[5]

While exceptional observational skills are no doubt integral to the pediatric orthopaedic surgeon's practice, there are inherent limitations in the subjective nature of OGA in the clinical setting. Instrumented gait analysis (IGA) provides a means to overcome these limitations by allowing for objective measurements of the various components of the gait cycle and quantification of an individual patient's deviation from normal locomotion. IGA can confirm or clarify diagnoses, alter treatment plans, and improve outcomes when incorporated into the preoperative workup and treatment plans.[8,10,11] This is especially true for axial plane abnormalities which are especially difficult to evaluate with observation alone.[7] For example, a child may be incorrectly diagnosed with a hip adduction contracture and dynamic knee valgus while gait is observed in the clinic, when, in actuality, the impairment is mostly increased femoral anteversion which is readily identified with IGA. Many experts feel that alterations in the coronal, sagittal, and axial planes are better elucidated with IGA, allowing for more precise clinical interpretation of a patient's gait impairment.

Instrumental gait analysis (IGA) can produce additional details unobtainable in OGA and may provide additional biomechanical insights into particular gait impairments. Foot deformities in cerebral palsy are commonly seen in the clinic, and some appreciation can be made by visual gait inspection, but more detailed pathophysiology can be determined with elements of a complete IGA, such as ankle kinematics, ankle kinetics, and pedobarography. Insights into the endurance and metabolic reserve of the patient can be elicited with oxygen consumption testing. These data can be compared with age-matched controls to highlight deviations from normal. Data from the same patient may be compared with different conditions of walking (e.g., barefoot, wearing braces, using a walker, etc.) and/or with different time points (e.g., preoperative versus postoperative). Variability of data throughout multiple gait cycles can also assist in detecting or confirming the amount of extrapyramidal pathology present (e.g., ataxia, dystonia, or other movement disorder). All these components of IGA potentially can provide the treating physician more information to help better care for children with CP and gait impairments.

Multiple studies have demonstrated the benefit of IGA in assisting with developing treatment plans for patients with disorders affecting gait, highlighting the important fact that IGA is not just a research tool but a valuable clinical tool.[8,10,11] However, it remains an underutilized resource, either due to lack of knowledge of its benefits, lack of access to a gait lab, or both.[9] The purpose of this paper is to provide details and definitions about the specific components of IGA and its use in the clinical care of children with CP.

Components of IGA

Standard Technology and Methods

The most basic component of the gait laboratory is a high-quality video camera. Standardized views, including those assessing the frontal and sagittal planes, should be part of a systematic methodology to capture the same video sequences of the patient's gait at each session. The laboratory needs to have a long enough walkway to ensure that the gait cycle is smooth and natural, and not forced into an artificial cadence to fit into a cramped space (see accompanying video).

The typical technology that is used in most IGA laboratories today is a passive motion capture system, where small markers are placed on anatomic landmarks, and infrared cameras are able to detect the position of each marker in three-dimensional space. These markers are then converted to a virtual skeletal model with coordinate transformation systems and anthropometric measurements of the patient (i.e., the conventional gait model). There are different but similar methods of placing the markers on specific anatomic landmarks across laboratories; however, the importance of the accuracy and reliability of the placement of these markers is one of the keys to high-quality data production in IGA labs. This virtual skeletal system, based on the marker position in space, can then be resolved to provide accurate joint angular data (trunk, pelvis, hip, knee, ankle) as a function of time throughout the gait cycle.

Kinematics

The term kinematics refers to the study of motion of an object. In the context of IGA, we use kinematics to denote the study of motion of a body part or joint. For example, we plot the functional knee range of motion of a patient with suspected crouch gait and observe a decrease in the amount of knee extension obtained during single limb stance and/or foot strike.

To obtain kinematic data, multiple reflective markers are placed on the patient's limbs, pelvis, and torso in a standardized fashion. Charge-couple device (CCD) cameras placed in the room are able to sense these reflective skin markers. The data from these cameras are processed with specialized computer software and will render three-dimensional (3D) information about the movement and orientation of the patient's individual body segments in space throughout the gait cycle. With each body segment represented by 3D coordinates, various data can be derived such as angles, angular velocity, or angular acceleration of a given joint.[6] Importantly, kinematic data can be calculated for motion couples in each of the three anatomical reference planes. For example, hip internal/external rotation, flexion/extension, and abduction/adduction can all be quantified and recorded.

Kinematic data is typically presented as a standard graphical display with the motion couple of the joint of interest (knee varus/valgus, for instance) plotted as a function of percentage of one full gait cycle on the horizontal axis. Although arbitrary, the gait cycle is typically conceptualized as beginning with foot strike (Initial Contact) of one limb and ending with the next subsequent foot strike of the same foot. A tracing of age-matched population normal values (or range of normal) is also plotted for comparison. In this way, when interpreting IGA data, a patient's gait alteration and deviation from normal motion of individual joints and segments can easily be seen.

Often, it is helpful to graphically display data from multiple gait cycles so that an idea of the consistency of the deformity may be appreciated. In many spastic conditions or in the setting of fixed contracture, a relatively consistent tracing is observed, whereas in patients with a high degree of extrapyramidal activity (e.g., ataxia), the tracings may be extremely variable. If subtle, this may be an important finding that may not otherwise be readily apparent on physical examination.

Temporal-distance parameters such as stride length, step length, and limb velocity are typically calculated and displayed compared to age-matched typically developed control subjects (Figure 1).

Kinematic plots can be shown grouped by plane, for example, all the transverse plane kinematics of the pelvis, hip, knee, and ankle shown together, followed by the frontal plane and sagittal plane. Or, the data can be shown grouped by joint, where all three planes are shown for each joint on a separate grouping of data, such as Hip (Figure 2), Knee (Figure 3), and Ankle (Figure 4).

Kinetics

Kinetics refers to the forces acting on a moving body. A force changes an object's velocity; in the absence of any force, it will keep moving at the same speed. This inertia–the tendency of an object to maintain constant velocity–helps the body move efficiently through the gait cycle. If a force is required to propel the body forward at one point in the gait cycle, that means another force is opposing the body's movement at a different part of the cycle.[12]

When the foot comes in contact with the ground, the two exert counteracting forces on each other. The ground reaction force (GRF)–the force exerted by the ground on the body in response to gravitational and muscular forces–always has an upwards vertical component, and its horizontal component can be directed medially versus laterally and forwards (fore) versus backward (aft). Moments are similar to forces, except where forces accelerate a body in one direction, moments cause

Figure 1. Temporal-Distance Data

Alfred I. duPont Hospital for Children's Gait Analysis Laboratory

Aggregate Temporal/Spatial Data

Patient Name:	First Last
I.D. #	0
Test Date:	11/10/20

Normal Height 167
Height 1 170

Nemours
Alfred I. duPont Hospital for Children
Nemours Children's Clinic

Comment: Barefoot - No Assisitive Device

Right Side Measures **Left Side Measures**

				Normal			
Step Length Avg (cm)	30.32 (3.64)			63.75-71.53	56.57 (1.97)		
Step Length Avg (Normalized)	0.18 (0.02)			0.39-0.43	0.33 (0.01)		
Stride Length Avg (cm)	86.85 (4.35)			127.77-142.55	86.96 (3.95)		
Stride Length Avg (Normalized)	0.51 (0.03)			0.77-0.85	0.51 (0.02)		
Forward Velocity Avg (cm/s)	88.05 (4.92)			117.44-145.26	88.45 (5.15)		
Forward Velocity Avg (/s)	0.52 (0.03)			0.71-0.87	0.52 (0.03)		
Cadence Avg (steps/min)	121.62 (4.47)			105.33-127.85	121.97 (4.69)		
Total Support Time (%)	68.39 (3.60)			57.59-61.67	52.76 (2.01)		
Single Support Time (%)	47.24 (2.01)			38.33-42.41	31.61 (3.60)		
Step Width (cm)	18.53 (0.90)			7.20-11.90			
Step Width (Normalized)	0.11 (0.01)			0.05-0.07			
GDI	91.74 (2.36)			90.00-110.00	68.70 (1.38)		
Gait Profile Score (Average)	8.19 (1.00)			5.30-7.38	13.31 (0.94)		
Arm Posture Score (Average)	18.88 (4.78)			12.30-18.38	15.54 (4.93)		

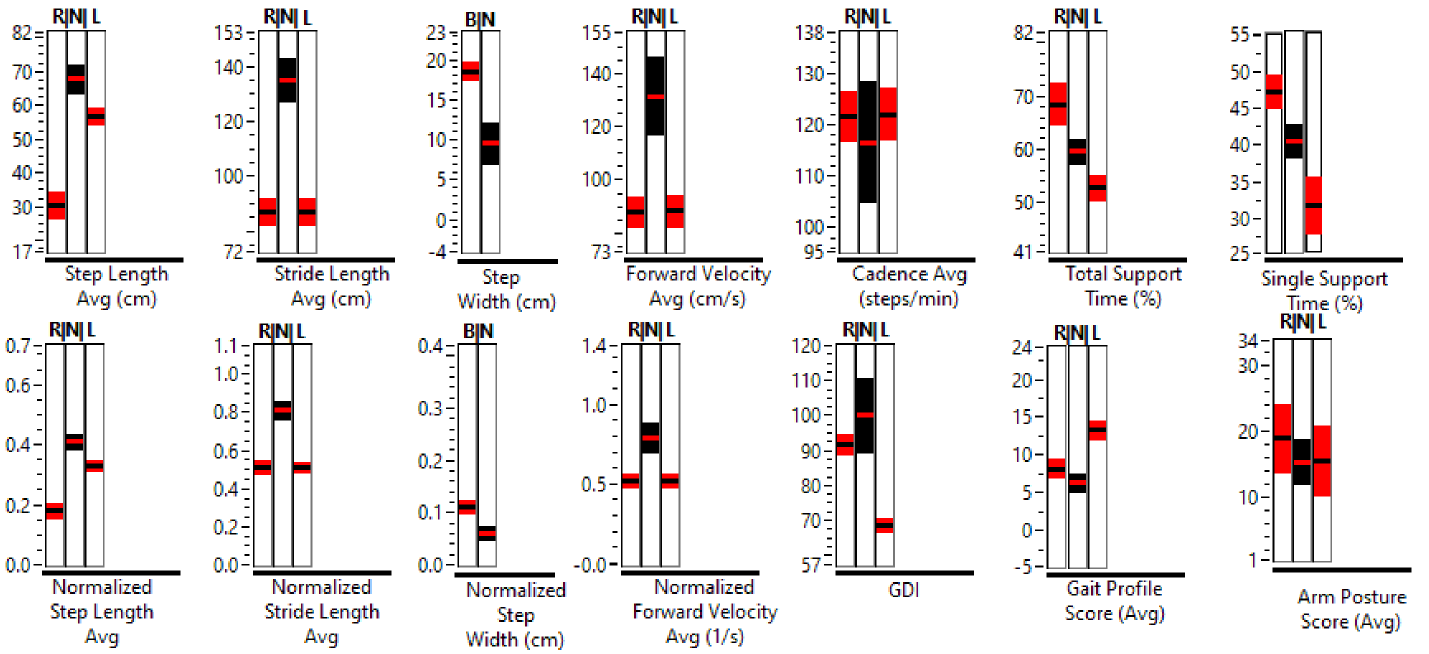
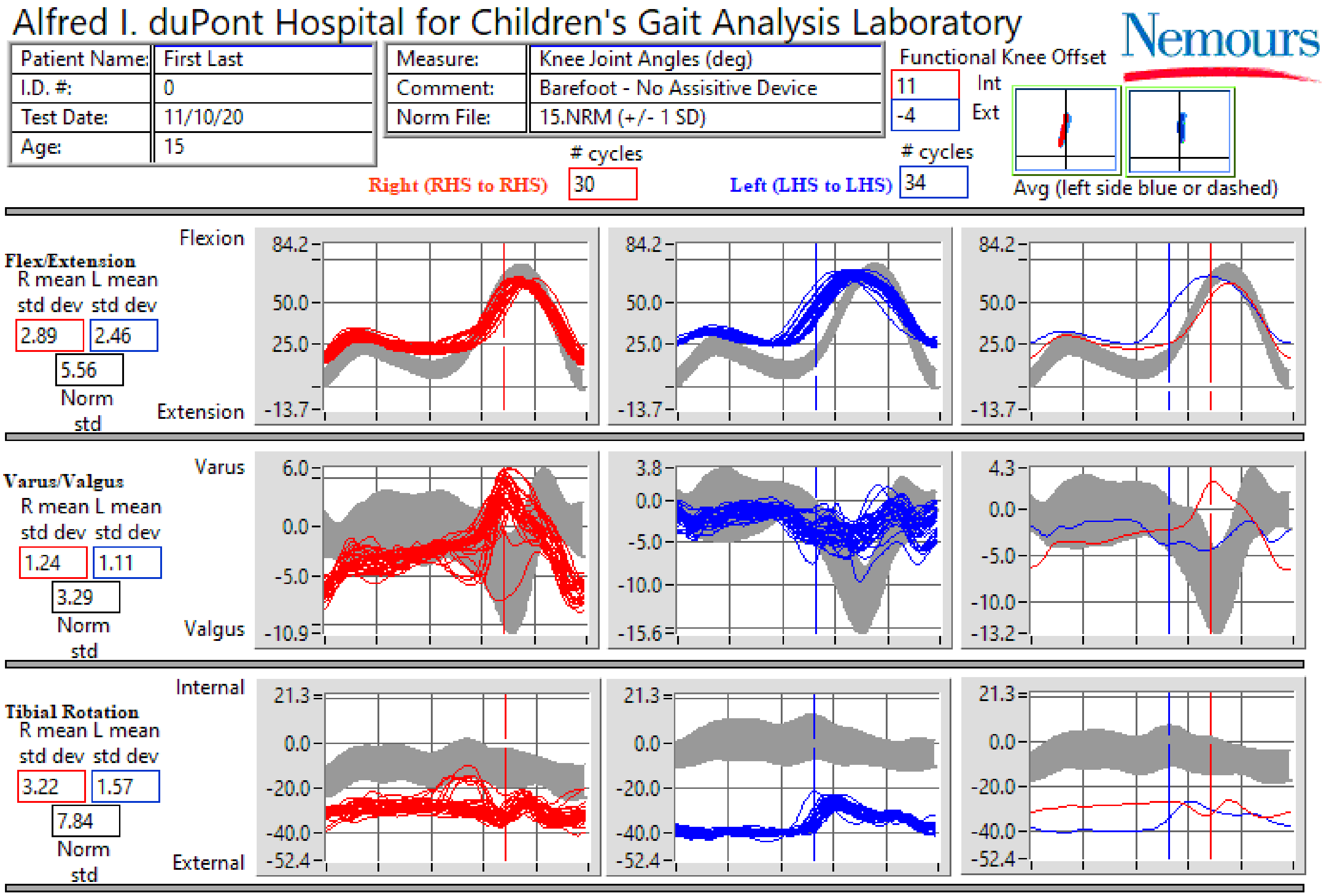


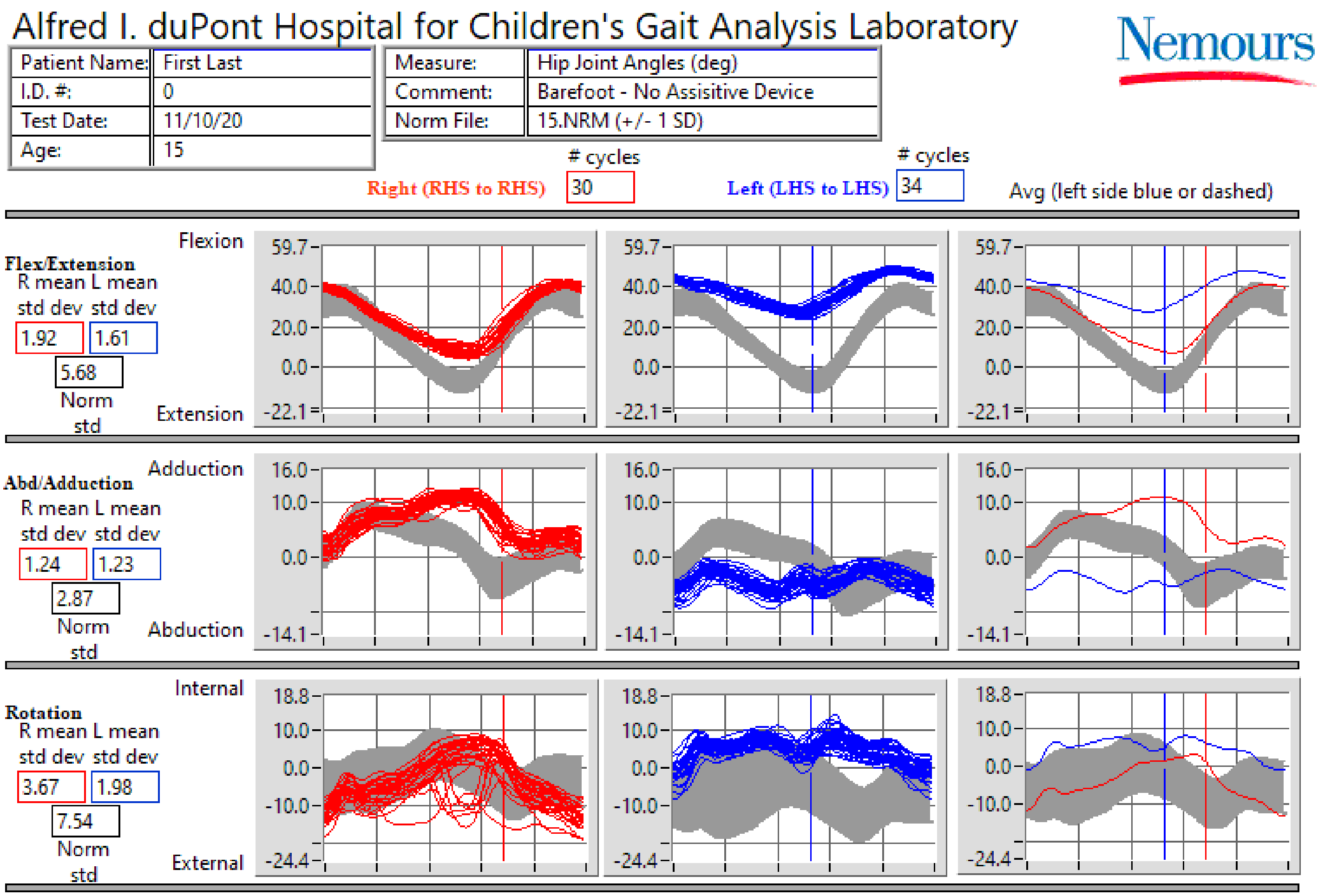
Figure 2. Hip Kinematics (Joint Angles)



rotational acceleration (a change in angular velocity) around an axis. Applying a force near a joint creates a moment, and the moment depends on the magnitude of the force and the perpendicular distance between the force's line of action and the joint's axis of rotation.

The net moment on the human body in gait is comprised of the GRF, each joint's center of rotation, and each body segment's center of mass, acceleration, and angular velocity.[13] In the laboratory, the patient walks on a surface that contains force plates with transducers to measure vertical force, fore-aft and medial-lateral shear (horizontal components of force), and torque. These values can be combined with kinematic and anthropometric data (e.g., leg length) to calculate the joint moment.[12] Kinetic parameters are typically reported as internal moments; the total moment is assumed to be exerted by all internal structures acting across the joint, including muscle activity, ligament stretch, and resistance from bony morphology or contractures. These total internal moments are what is required to counter external moments acting on the joint. Figure 5 displays an example of internal joint moments at the ankles. The body moves as linked system of units and depends on the combined effects of all moments acting at all joints.[14] For example, in terminal stance, as the body progresses forward over the planted foot, the triceps surae contracts eccentrically to hold back the tibia (internal ankle plantarflexion moment), and the knee goes into relative extension due to joint connections and inertia. This physical effect is termed the plantarflexion-knee extension couple.

Figure 3. Knee Kinematics (Joint Angles)



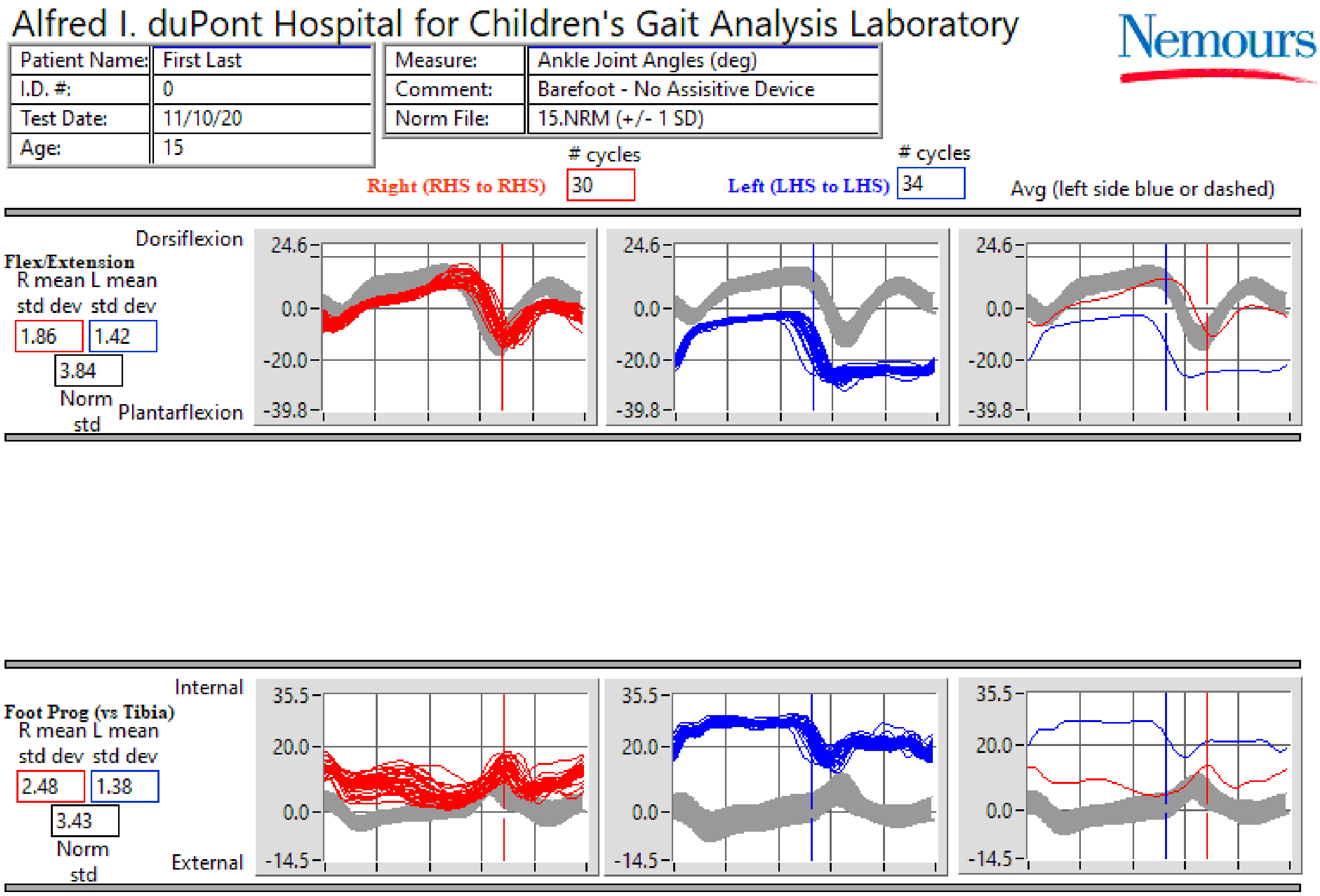
The moment data of the ankle can then be used to calculate the power generated and absorbed at a given joint which is determined by multiplying the joint angular velocity by the joint moment. Typical findings can correlate with specific gait impairments, and these correlations can be intuitive or can be quite complex. For example, patients with weak plantarflexor strength will typically have low ankle power but understanding power generation and absorption at the hip and knee can be difficult (Figure 6).

Electromyography

Electromyography (EMG) detects the electrical impulse produced by a muscle as a representation of its activity. When a nerve innervates a muscle fiber at the motor end plate, the negative electrical potential difference across the cell membrane temporarily reverses to a positive potential.[12] This action potential travels along the whole length of the fiber and creates an impulse throughout the muscle that diminishes in amplitude with increasing distance from the depolarized section of nerve. Thick skin and soft tissues further impede and reduce signal magnitude. When two electrodes are placed, there will be a difference in potential between them since they are different distances away from the source of the impulse. The greater the distance between the electrodes, the larger the detected signal but at the expense of reduced specificity and potentially picking up signals from other muscles nearby.

Surface electrodes are generally adequate for measuring the activity of most muscle groups in clinical gait analysis, e.g., gastrocnemius-soleus or adductors. Cross-talk from neighboring muscles can pose an issue, depending

Figure 4. Ankle Kinematics (Joint Angles)



on electrode placement as described above, but usually this does not influence clinical decision-making.[15] Deeper muscles (e.g., tibialis posterior or flexor digitorum profundus) are too deep for surface electrodes to detect and require the placement of fine-wire electrodes. However, the discomfort caused to the patient by this procedure may preclude the benefit of fine-wire EMG data. It is technically demanding and frequently not tolerated well by young children.

To time the EMG data to the gait cycle, foot switches or similar timing devices are used. The data may be presented raw or undergo signal processing (e.g., low-pass filter to remove residual low-frequency movement artifact, followed by averaging). Clinicians may prefer to interpret the raw form of data since signal processing has the risk of concealing artifact rather than removing it. EMG data augments kinematic and kinetic data to provide a more comprehensive understanding of a patient's gait. Determining which muscle is active or inactive during a particular motion is essential for prescribing the correct intervention for a problem (Figure 7). It is also critical for deciding which muscles should be used as the "motor" in a tendon transfer. For example, a rectus femoris-to-hamstring transfer may benefit a child with a stiff-knee gait if there is rectus femoris overactivity in swing phase. However, if the child has swing phase activity of other quadriceps muscles or co-contraction of the hamstring muscles, a rectus femoris transfer would have an unpredictable outcome.

Pedobarography

Two prerequisites of gait–stance phase stability and prepositioning of the foot at initial contact–may be indirectly assessed by measuring the distribution of foot

Figure 5. Kinetic/Moment Data of the Ankle

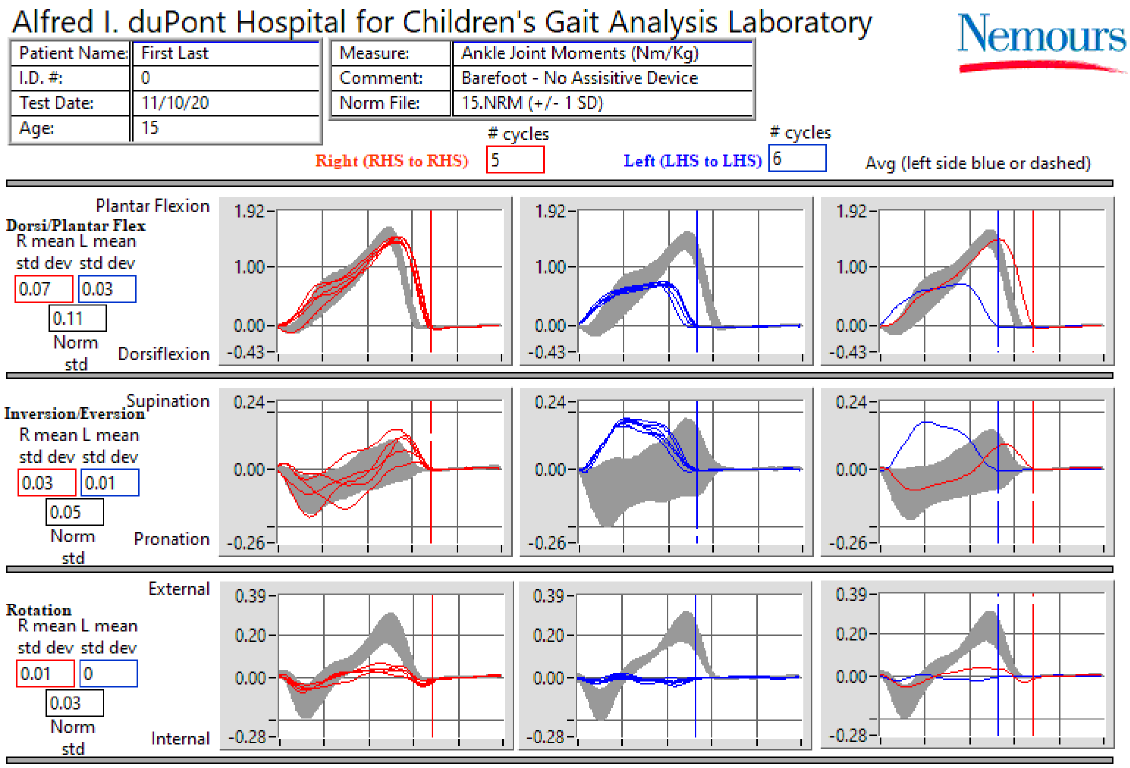


Figure 6. Power Plots of the Ankle

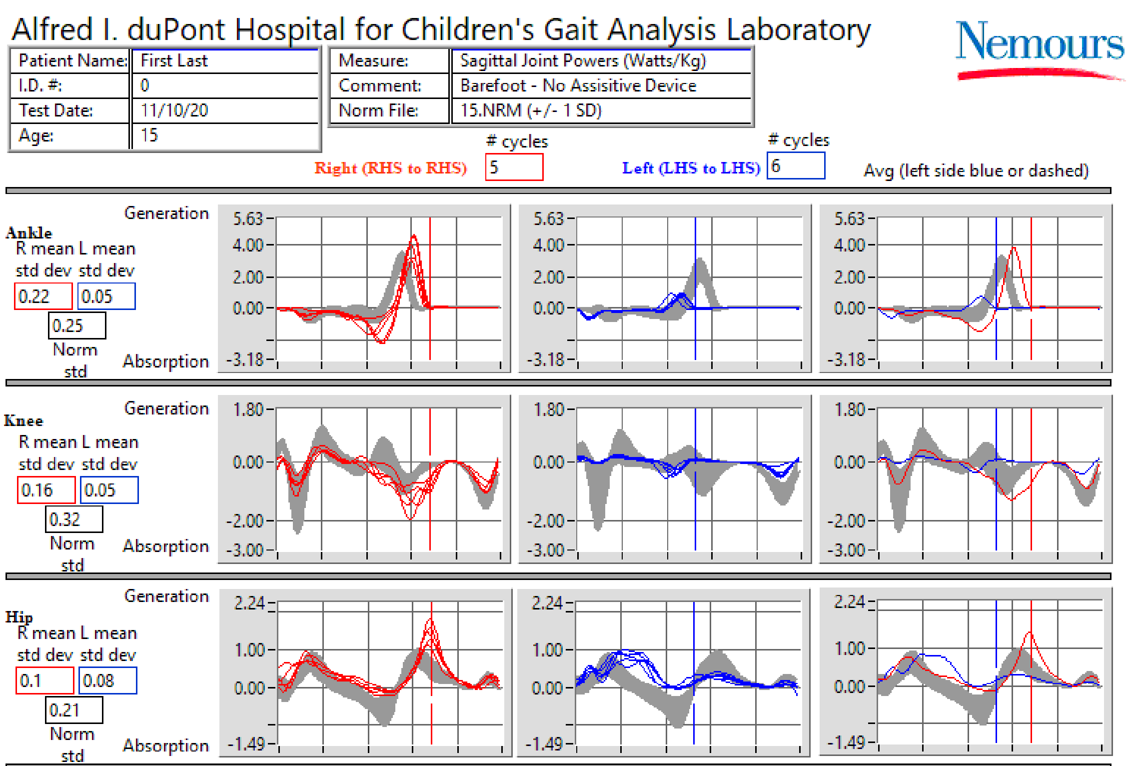
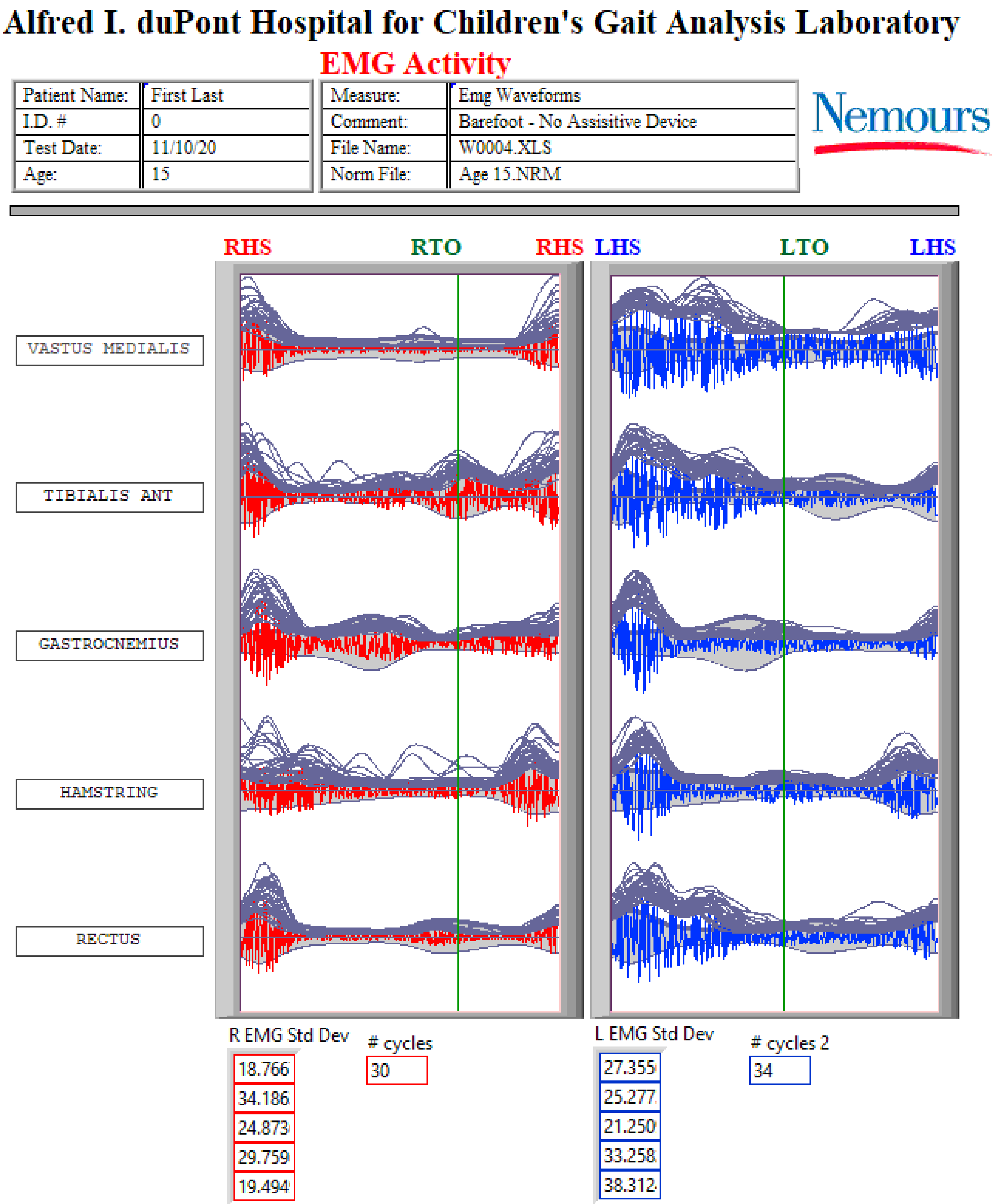


Figure 7. EMG Waveforms



pressures (pedobarography). The foot connects the body with the ground through an area of contact, and the pressure pattern of this contact area provides a form of objective insight into foot function. Since pedobarography can quantify varus, valgus, and heel contact position, it is particularly helpful for subtle varus or valgus hindfoot deformities and monitoring the changing foot postures in children with cerebral palsy.[16]

Two main types of foot pressure measurement systems exist: either the patient wears force transducers inside their shoes, or they walk on a force plate transducer.[15] Each has its benefits and disadvantages but yields similar information. In plate transducer systems, a larger sensing area typically comes at the expense of less accuracy for the absolute pressure measurement.[16] Systems with a smaller area but greater accuracy and sensitivity are likely more appropriate for patients developing sores on their feet (e.g., insensate feet secondary to diabetes or spina bifida). The pressure data is diagrammed on a colored grid, with different colors signifying various pressure concentrations. In dynamic pedobarographs, the center of pressure line depicts the sequential movement of the center of pressure from the time of initial contact until toe-off[16] (Figure 8).

Balance and Consistency

Instrumented motion capture analysis can be useful in determining balance assessments. Sophisticated modeling of the center of mass and center of pressure has been described and can be useful in a variety of pathologies, including vestibular dysfunction.[17] Balance assessment in the setting of CP and IGA typically assesses the variation of the center of mass with respect to the anterior-posterior and medial-lateral foot placement; this effectively determines the distance the center of mass deviates from a straight line and can give some assessment of balance during gait (Figure 9).

Metabolic Assessment/Energy Expenditure

Energy consumption is one of the prerequisites for typical gait.[1] Any gait impairment will force the patient to expend more energy. Achieving a normal gait aims to decrease stresses on muscles and joints and, most importantly, reduce the energy required to move.[15] Energetics–the measurement of energy expenditure–occurs while the patient is walking and may be characterized by: (1) the amount of oxygen consumed and carbon dioxide expired,[16] (2) the patient's pulse when it has reached a steady state,[21] or (3) the mechanical cost of work, as determined by force plate data.[18]

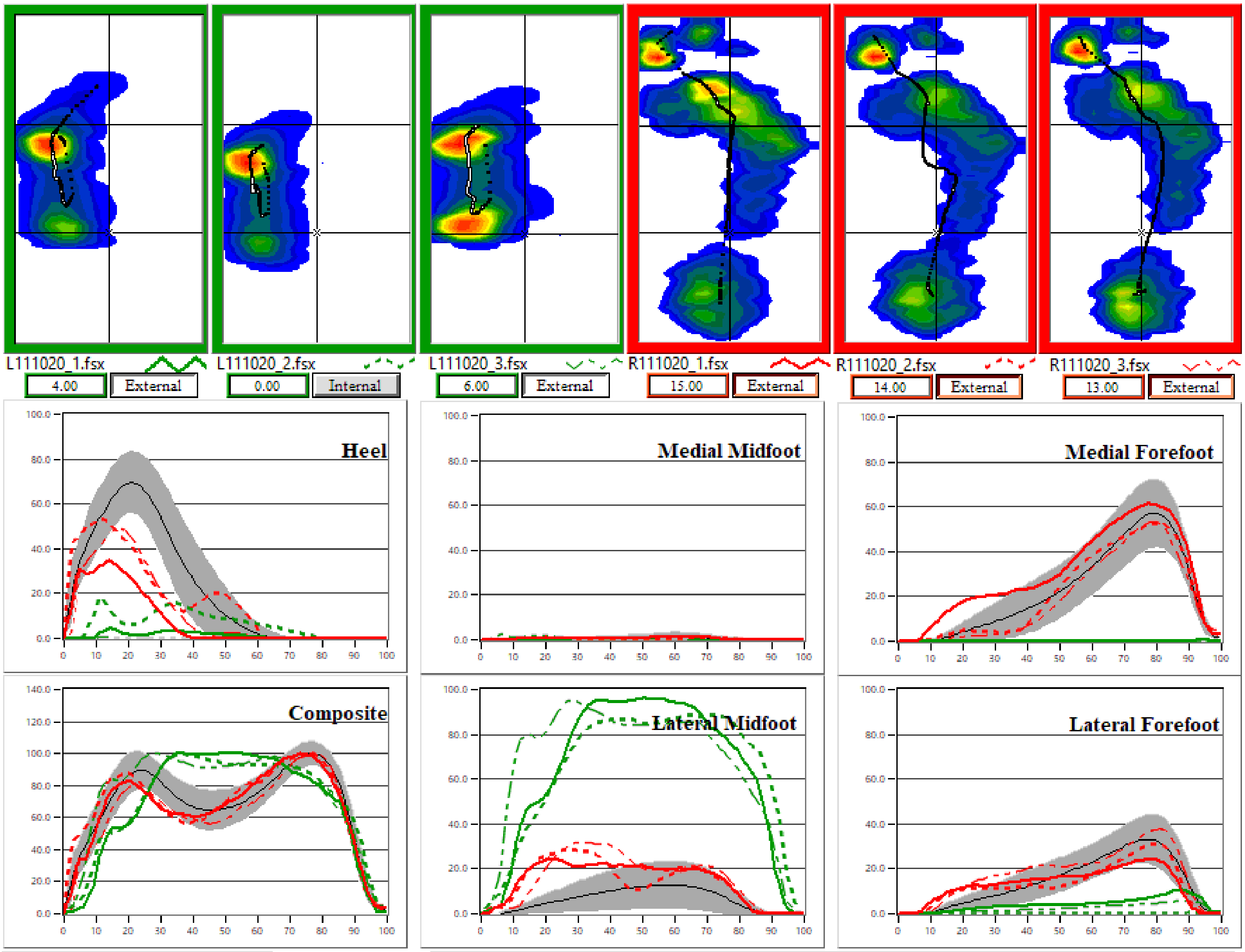
Modern calorimetry systems utilize small telemetry devices that are portable, easily worn during gait and exercise, and give output of continuous oxy gen use, carbon dioxide excretion, respiratory rate, volume of expired air, and heart rate.[16] Other systems may use a collection apparatus on a metabolic cart pushed by a technician walking next to the patient. Because oxygen consumption varies according to the size of the person, it should be normalized to body weight or by height or leg length.[19] Limitations of the indirect calorimetry method include the need to wear a breathing apparatus and the potential variability of oxygen consumption throughout the exercise trial, depending on the subject's physical condition that day and other factors like anxiety.[15] Walking velocity may affect oxygen cost, although within a range of 60-140 cm/s, an individual's oxygen cost should not significantly change.[20]

The oxygen cost index (O_2 Index) is a normalized measure of normalcy of oxygen consumption (normal = 1) and is a useful scalar assessment of an individual's overall metabolic reserve[21] (Figure 10). Measuring energy expenditure before and after an intervention is a valid, objective method of documenting outcomes. However, energy expenditure is ultimately only one facet of an individual's overall function.[22]

Foot model

Traditional gait models include a simple marker set for foot and ankle motion. While this analysis will capture two-dimensional motion of ankle in flexion/extension, more advanced foot deformities are unable to be truly assessed with a simple model. For example, the simple

Figure 8. Pedobarographic Data



Name First Last
Test Date 111020
Patient ID 0
Age 15

* The data in the graphs are represented as a percentage of the total load assumed by the foot for each segment.
* The data in each graph begins with heel strike and ends with toe off (stance). Data were dilated to 100 points (x axis).
* Mean +/- 1 SD
* Age bands: 2y, 3y, 4y, 5y, 6-8y, 9-11y, 12-17y, 18-21y

Output

Summary Table Left				Comment			Right			Comment			Normal
Time of Heel Rise	57.0	78.0	1.0	Normal	Late	Early	39.0	62.0	58.0	Early	Normal	Normal	48.0 - 64.6
Heel Impulse	1.7	9.1	0.0	Low	Low	Low	12.1	24.8	19.3	Low	Low	Low	26.5 - 42.0
Varus-Valgus Foot Postition	-102.	-101	-98.3	Varus	Varus	Varus	5.1	-12.2	-27.2	Normal	Normal	Varus	-17.1 to 30.8
Foot Progression	4	0	6	Normal	Internal	Normal	15	14	13	External	External	External	0.5 to 8.8
Stance Time	0.54	0.58	0.54	Short	Short	Short	0.70	0.70	0.67	Normal	Normal	Normal	0.6 to 0.8

Comments 1

11/10/20 No Assisitive Device

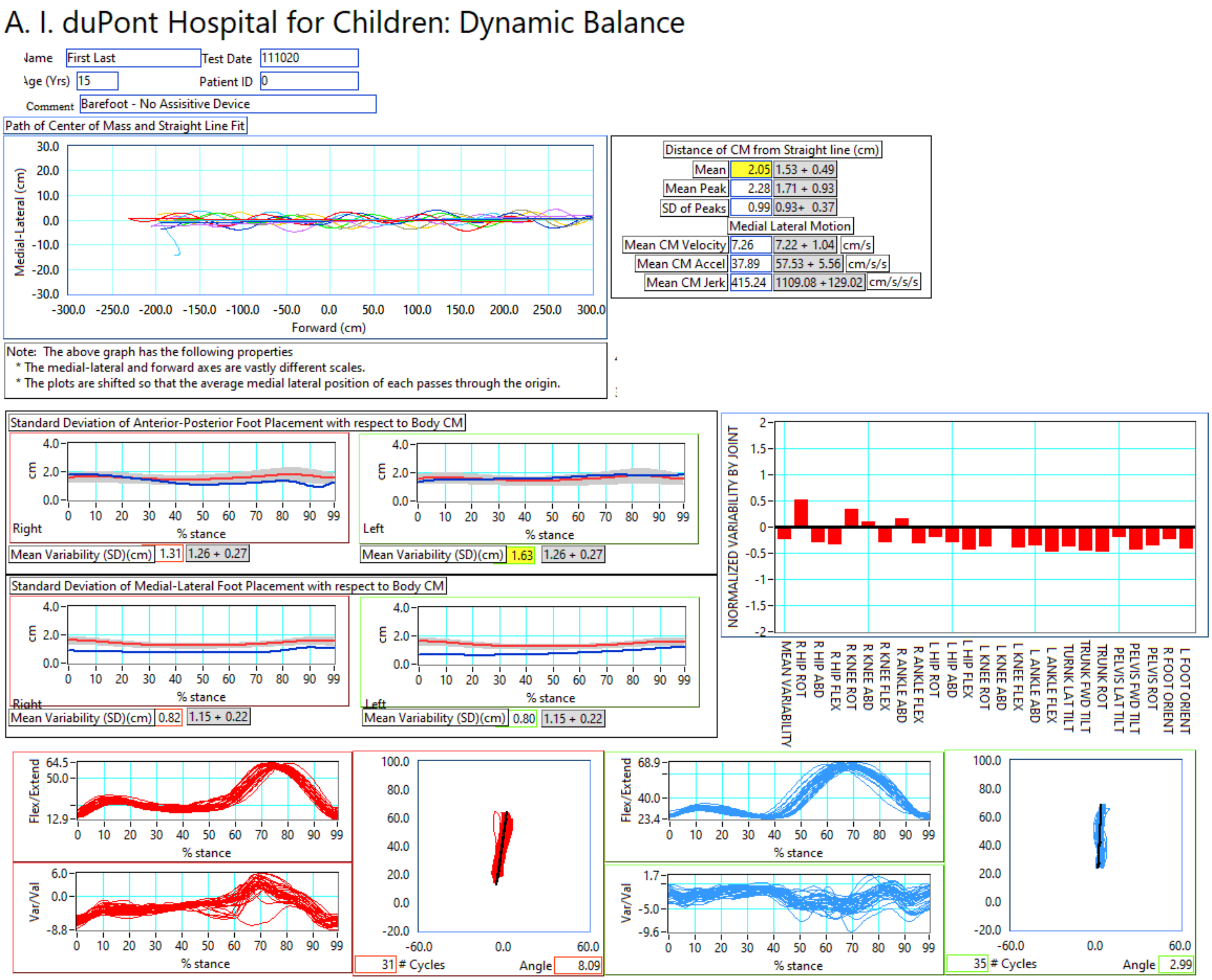
Comments 2

11/10/20 No Assisitive Device

Comments 3

11/10/20 No Assisitive Device

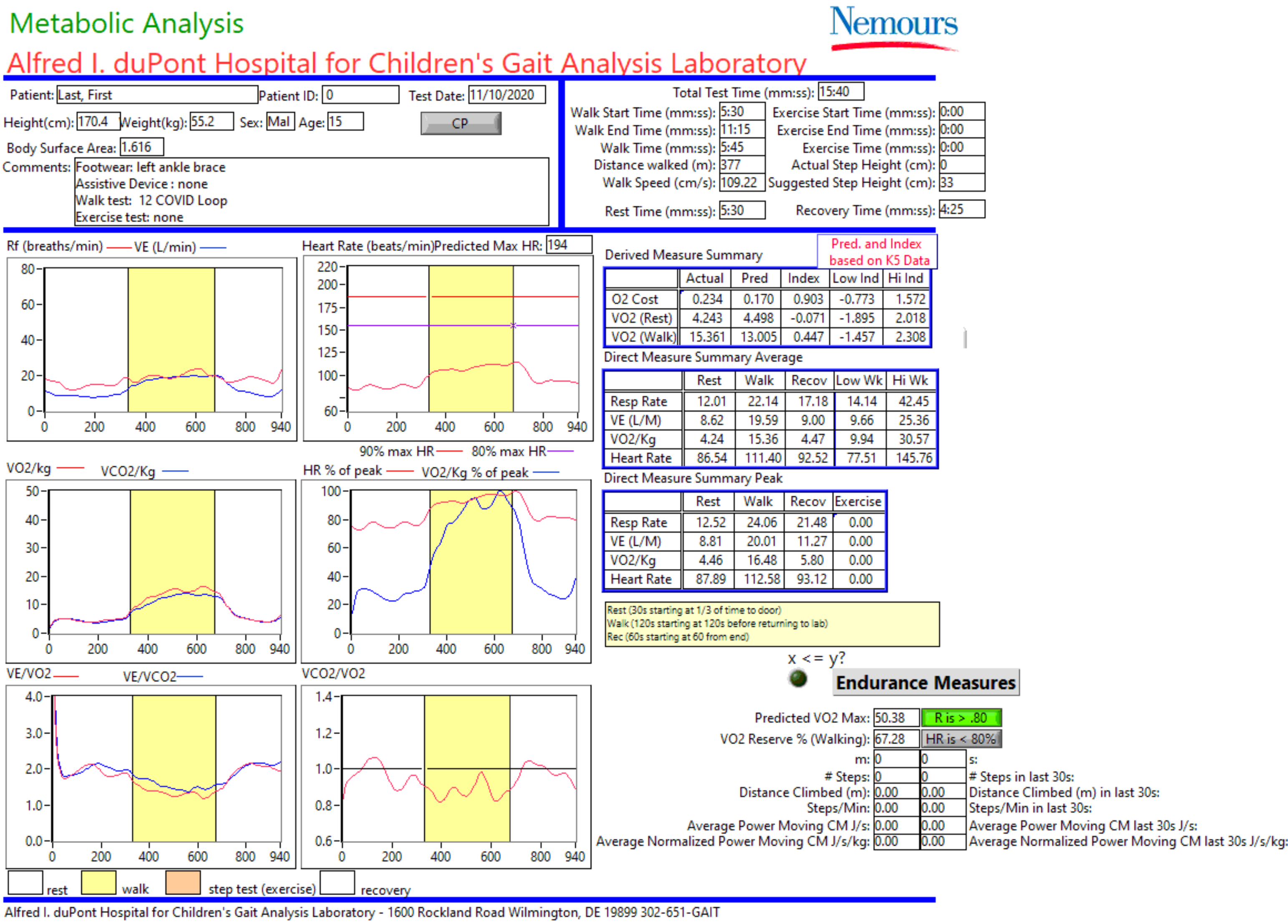
Figure 9. Balance and Consistency Assessment



marker set does not accurately capture hindfoot valgus or forefoot abduction and may mistake midfoot break for true ankle dorsiflexion. Because of these difficulties, new multi-segmented foot models have been described. These include smaller markers placed on anatomic landmarks along the foot and ankle, allowing for more sophisticated foot and ankle modeling. For example, hindfoot varus and valgus, arch height, hallux varus and valgus, and forefoot adduction and abduction can be modeled with this advanced marker set (Figure 11).

The clinical use of foot models is still under development as more centers get additional expertise and experience with these advanced methods and protocols. Because of the small distances between the anatomic landmarks of the foot and ankle, foot models can be quite sensitive and prone to errors from markers placed even a few millimeters off in error. However, there are several reports that suggest multi-segment foot modeling will likely be used more and more in the future to provide more sophisticated foot and ankle assessment in CP.[23]

Figure 10. Metabolic/Oxygen Consumption Analysis



Activity Monitoring

Motion analysis laboratories can measure physical function to a high level of detail; however, there is something artificial about measuring activity in a laboratory setting. The true function of a patient with CP in the community, as defined by the International Classification of Function, Disability, and Health (IC F), emphasizes that activity and participation in the community are vital goals.[3] Their activity level and participation in society should be an important aspect of our assessment of their overall function. Physical activity monitors (on bracelets, watches, phones, etc.) are common in our society now.

Similar technology such as simple pedometers can also give meaningful information about step counts and overall physical activity. Commercially available research activity monitors such as StepWatch have been demonstrated to accurately measure walking ability and community activity for patients with CP[24] (Figure 12).

Some gait labs are using this activity monitoring as an adjunct for measurement of physical function, primarily to measure outcomes of surgical treatment by measuring rehabilitation and recovery.

"Wearables" are braces or devices that are worn on a person and measure electronic health data. In orthopaedics, wearables are being used more in total joint arthroplasty and sports. These devices can determine temporal-distance parameters such as stride length, step length, cadence, and kinematic data such as knee flexion and extension.[25] Future use of this technology could be used to assess declining function in patients with CP before surgery and could be used as an important adjunct of surgical indication.

Case Example

This case example is a 15-year-old male with hemiplegia who presented to our clinic for the first time. He has no history of orthopaedic surgery or Botox treatment in the past which is a bit unusual for a 15-year-old with hemiplegia. The family presents with gait concerns such as his foot turning in as well as some tripping. He does have some occasional pain in his left lower extremity. Pertinent physical exam findings show asymmetric hip internal rotation at 70 degrees with external rotation of 20 degrees on the left. He has a 20-degree knee flexion contracture on the left and a 30-degree equinus contracture with an equinovarus foot deformity with forefoot adduction. He has more symmetric hip rotation on the right and a mild knee flexion contracture on that side with a foot that can come to neutral at the ankle. He has clear asymmetric poor motor control on the left lower extremity. He has diffuse increased tone on his left lower extremity.

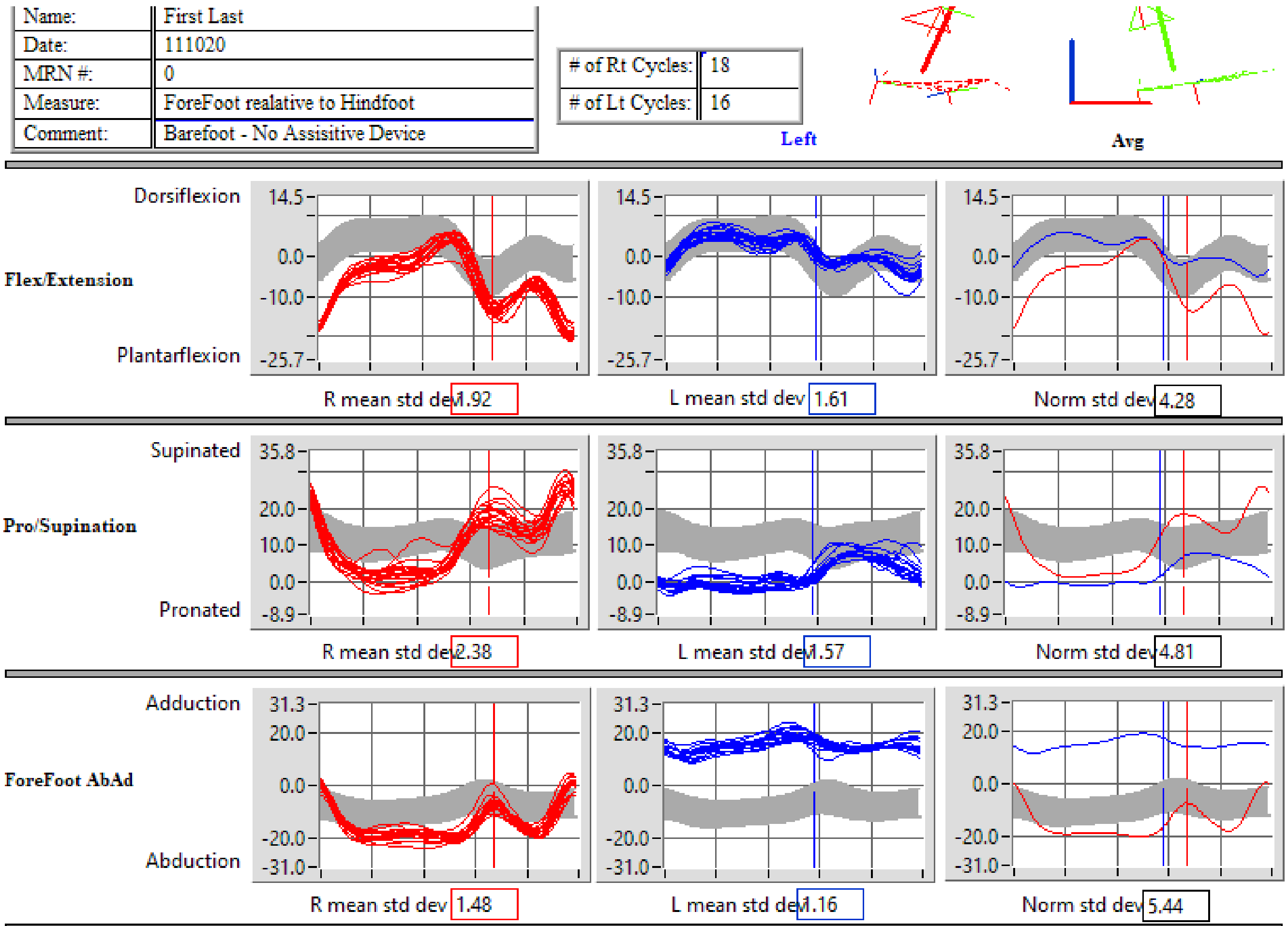
His temporal spatial data shows decreased velocity, decreased stride length, and decreased step length bilaterally. He has a normal gait deviation index (GDI) on the right but a decreased index on the left (Figure 1). His hip kinematics show a lack of full hip extension and late stance (Figure 2). Despite his internal rotation on physical exam, he has near normal hip rotation. His knee kinematics show increased knee flexion at initial contact and midstance, along with external tibial torsion bilaterally, left greater than right (Figure 3). Ankle kinematics show equinus on the left foot (Figure 4), and ankle kinetics show a decreased peak plantarflexion moment and early plantar flexion moment rise, typical of equinus (Figure 5). His EMG is abnormal with an early onset gastrocnemius signal bilaterally, as well as some out of phase tibialis anterior on the left (Figure 7). His pedobarograph shows significantly abnormal plantar pressures with most of his pressure over his lateral left midfoot (Figure 8). The patient demonstrated remarkable consistency and overall good dynamic balance with respect to the anterior-posterior and medial lateral placement of his feet relative to his body center of mass (Figure 9). His metabolic analysis shows that he has a normal oxygen cost index of 0.903 with an appropriate response of his heart rate and respiration to increased exercise (walking) (Figure 10).

Discussion

Children with cerebral palsy and other developmental disabilities have very complex gait impairments as a result of the underlying neurological disability. A thorough and complete evaluation of all of these gait impairments can be difficult with observational gait analysis alone, and instrumented gait analysis can be helpful to guide treatment decisions.[15] This review has discussed several of the features and components of typical instrumented gait analysis done today as a part of the comprehensive care of children with CP.

There have been several studies that have assessed the reliability, accuracy, and effectiveness of instrumented gait analysis in the care of children with CP. Deluca et al. reviewed 91 patients who had been evaluated by experienced surgeons and had recommended surgery. Those recommendations were then compared to the recommendations from gait analysis which showed that the surgical recommendations changed 52% of the time with an overall reduction in the amount of surgery recommended.[26] Wren et al. also demonstrated that gait analysis alter treatment plans 89% of the time of patients with CP.[10] These results provide a stronger level of evidence demonstrating that gait analysis changes treatment decision-making and also reinforces decision-making when it agrees with the surgeon's original plan.

Figure 11. Foot Model Kinematics

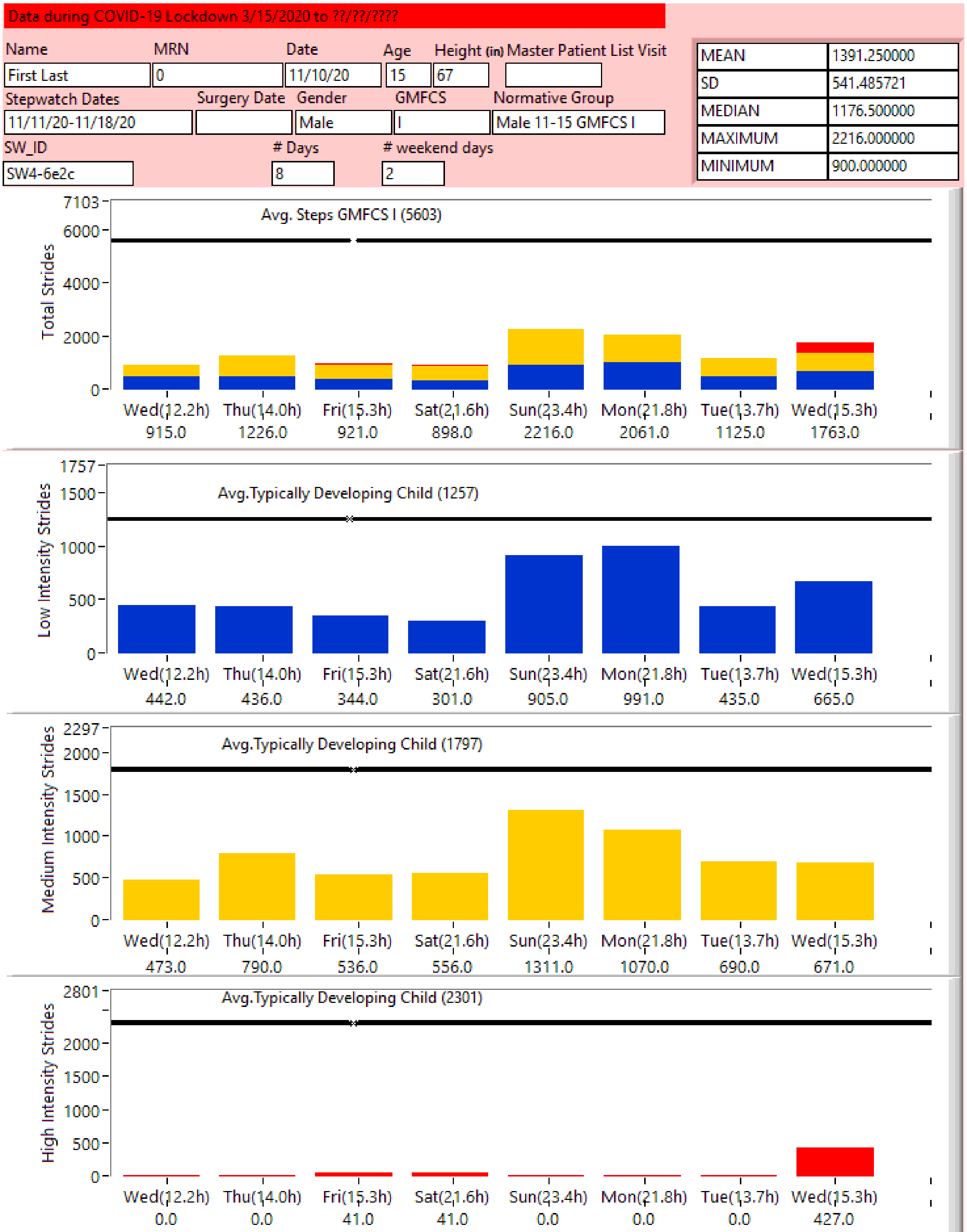


Further studies from that same group also demonstrated that instrument gait analysis was not only helpful in preoperative surgical planning, but it could also be useful in planning postoperative rehabilitation and was quite important in the assessment of surgical outcomes.[11] This randomized clinical trial of 156 patients demonstrated that outcomes of physical function, gait assessment, and quality of life were improved in the group whose surgery was guided by IGA.

Niklasch et al. investigated the effects of using IGA on determining the amount of rotation for femoral osteotomies in children with CP. They demonstrated superior outcomes when IGA was used to determine specific treatment goals compared to surgical planning based only on physical exam.[27] De Morais Filho further assessed the effects of whether IGA recommendations were followed for children with CP.[28] In their series, the patients whose surgical plan followed the recommendations of IGA had better improvements in gait outcomes. Lofterod and Terjesen led their group to rigorously analyze treatment plans directed by physical exam with those recommended by IGA.[29] The IGA group demonstrated a 13% reduction in the number of recommended procedures, specifically less boney procedures.

In conclusion, appropriate orthopaedic care for children with complex gait impairments, such as those typically seen in children with cerebral palsy, can be difficult. A thorough comprehensive gait assessment is imperative for determining treatment strategies for these children. Instrumented gait analysis can provide significant data and information above and beyond that from observational gait analysis that can help provide structure for

Figure 12. StepCount Activity Monitoring



determining appropriate surgical care plans for children with CP.

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