Chapter 17

QUALITATIVE AND QUANTITATIVE METHODS OF ASSESSING GAIT DISORDERS

*Florent Moissenet[1] and Stéphane Armand[2],**

[1]CNRFR – Rehazenter, Laboratoire d'Analyse du Mouvement et de la Posture,
Luxembourg, Luxembourg
[2]Willy Taillard Laboratory of Kinesiology,
Geneva University Hospitals and Geneva University, Switzerland

ABSTRACT

The management of patients with gait disorders need the identification and the understanding of gait deviations. It is based on the assessment of gait disorders. This chapter reviews the main methods and tools to assess these disorders. Firstly, the qualitative methods are presented, including the video, the questionnaire-based scales and the observation-based scales. Secondly, the quantitative methods are outlined, including the measurement of the spatiotemporal parameters, kinematics, kinetics, EMG, plantar-pressures and other outcomes. Finally, the most advanced clinical examination in order to assess and analysis gait disorders—clinical gait analysis—that uses several synchronised quantitative tools, is presented with its clinical relevance and its limitations.

Keywords: gait disorders, gait assessment, gait deviations, kinematics, kinetics, EMG, clinical gait analysis

KEY POINTS

- The management of patients with gait disorders need the identification and the understanding of gait deviations.

* Corresponding author: Stephane Armand, PhD Willy Taillard Laboratory of Kinesiology, Geneva University Hospitals and Geneva University, Rue Gabrielle Perret-Gentil 4, 1205 Geneve, Switzerland; Email: Stephane.Armand@hcuge.ch

- Qualitative methods are the video, the questionnaire-based scales and the observation-based scales.
- Quantitative methods are the measurement of the spatiotemporal parameters, kinematics, kinetics, EMG, plantar-pressures and other outcomes.
- Clinical gait analysis uses several synchronised quantitative tools and it represents the most advanced clinical examination.

17.1. INTRODUCTION

Gait is a complex movement requiring the interaction of numerous body structures and systems. Indeed, the movement necessary to walk requires the generation of external forces which are created by segments motions around joints thanks to a set of muscular contractions.

These contractions are ordered by the peripheral nervous system which is modulated by the central nervous system. Moreover, peripheral and central nervous systems have to integrate the information from the proprioceptive, vestibular and visual systems.

If one or several of these structures or systems are impaired, such is the case in cerebral palsy, the person will present movement disorders including gait disorders or incapacity to walk. According to these impairments, the role of the clinician will be to allow, restore or save the walking capacity and performance. A simple overview of the management of patients with gait deviations is illustrated in Figure 1.
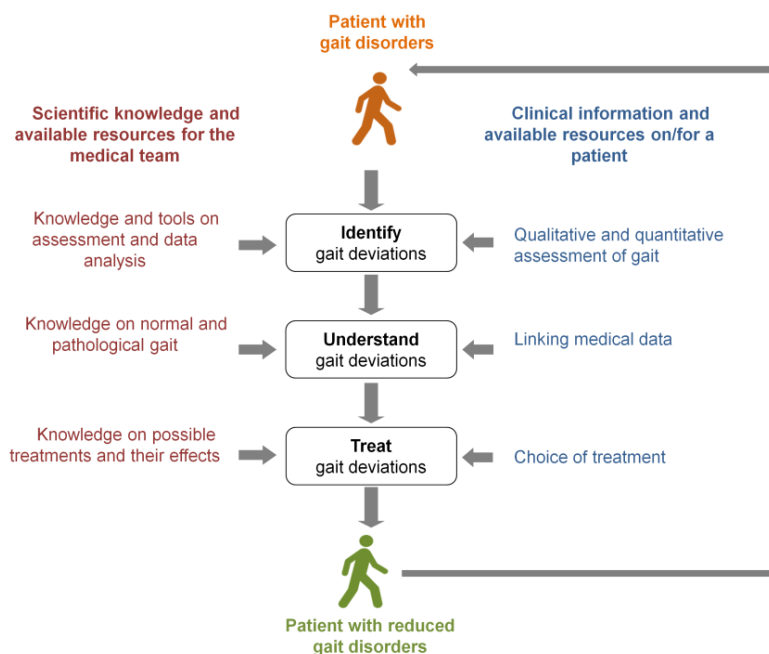

Figure 1. Management of patients with gait deviations.

The first step of this process will be to identify these gait deviations. This identification implies the assessment of gait that could be performed with different methods according to

numerous factors such as the level of complexity of the gait disorders, the available resources, the capacity of the patient to walk and the desired level of precision.

The second step will be to understand these gait deviations. The understanding of gait deviations implies establishing the relationship of different types of medical data, such as data from clinical gait analysis, physical examination or imaging results.

The interpretation process of gait deviations is complex and requires excellent knowledge on normal and pathological gait according different domains such as physiology, anatomy, neurology, orthopedics and biomechanics.

The third step will be to choose the best therapeutic approach according both steps 1 and 2. This simple process of management of gait disorders can be integrated into more advanced and general framework such as the International Classification of Functioning, Disability and Health (ICF) that proposes a classification of the health components of functioning and disability (Figure 2).
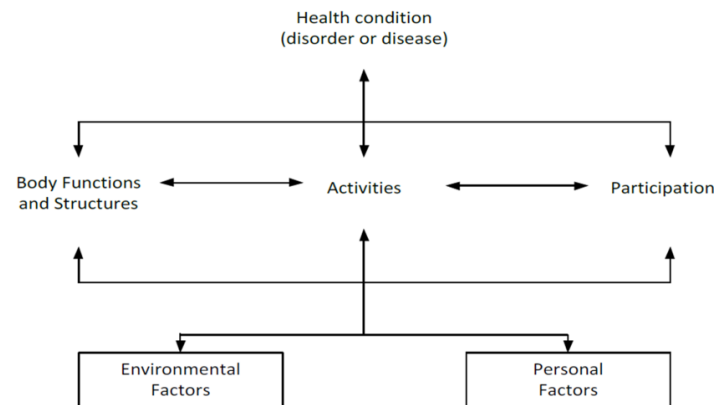

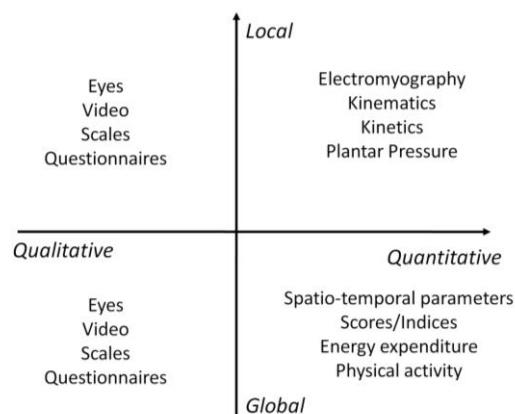Figure 2. International Classification of Functioning, Disability and Health (WHO, 2001).

Figure 3. Classification of methods and tools to assess gait disorders.

The aim of this chapter is to focus both methods and tools for assessing gait disorders in cerebral palsy that can provide qualitative or quantitative, local or global outcomes of gait disorders (Figure 3).

17.2. QUALITATIVE GAIT ASSESSMENT

Qualitative gait assessment is useful in clinical practice since it allows having an overview of the patient abilities in a fast manner, without or with minimum equipment. These tools can be divided in two categories: questionnaire-based scales and observation-based scales. Moreover, simple video equipment is often used in clinical setting to record an overview of the gait and to support the use of other qualitative tools.

Questionnaire-Based Scales

Questionnaire-based scales aim attributing an overall score to a set of items listed in a questionnaire.

Many questionnaires are available and evaluate the patient's capacities when walking or performing a walking-related task. They can be self-reported or proxy-reported depending on the need and the cognitive capacities of the patient. In most cases, the evaluated items can be related to the different domains of the ICF.

Questionnaires can be global, focusing on gait as one task among other, or focal, with a specified analysis of gait capacities. On one hand, quality of life (or life participation) questionnaires allow focusing on different domains of the ICF. For example, the Pediatric Evaluation of Disability Inventory (PEDI) [1], the Activities Scale for Kids (ASK) [2], the Pediatric Quality of Life inventory (PedsQL) [3] or the paediatric version of the Functional Independence Measure (WeeFIM) [4], measure the self- or proxy- perceived performance when realizing a set of daily life activities. On the other hand, some other questionnaires focus more specifically on the locomotion ability in the activity domain of the ICF.

For example, the Gross Motor Function Classification System (GMFCS and the expanded and revised version GMFCS-ER) [5, 6], the Gillette Functional Assessment Questionnaire (FAQ) [8], the Functional Mobility Scale (FMS) [9] or the ABILOCO-Kids [7], measure the locomotion ability through a set of items representing different mobility contexts (Table 1). Anyway, the results of these questionnaires, self-reported or proxy-reported, are often affected by the subjectivity inherent in these tools. In this sense, it is essential to use an adapted (e.g., to any age or any disorders) and validated translation of the selected questionnaire to ensure a perfect understanding.

Observation-Based Scales

Observation-based scales aim evaluating the patient gait pattern or ability regarding a set of items through direct or indirect (i.e., video recorded) observations. They give rise to a classification by sorting the patient in a predefined group, or to an overall score based on the results.

Table 1. Left: Descriptors of the Gross Motor Function Classification System Expanded and Revised between 6th and 12th birthday [5, 6] – Right: Items evaluated in the ABILOCO-Kids [7]

Descriptors
GMFCS Level I Children walk at home, school, outdoors and in the community. They can climb stairs without the use of a railing. Children perform gross motor skills such as running and jumping, but speed, balance and coordination are limited
GMFCS Level II Children walk in most settings and climb stairs holding onto a railing. They may experience difficulty walking ling distances and balancing on uneven terrain, inclines, in crowded areas or confined spaces. Children may walk with physical assistance, a hand-held mobility device or used wheeled mobility over long distances. Children have only minimal ability to perform gross motor skills such as running and jumping
GMFCS Level III Children walk using a hand-held mobility device in most indoor settings. They may climb stairs holding onto a railing with supervision or assistance. Children use wheeled mobility when traveling long distances and may self-propel for shorter distances.
GMFCS Level IV Children use methods of mobility that require physical assistance or powered mobility in most settings. They may walk for short distances at home with physical assistance or use powered mobility or a body support walker when positioned. At school, outdoors and in the community children are transported in a manual wheelchair or use powered mobility.
GMFCS Level V Children are transported in manual wheelchair in all settings. Children are limited in their ability to maintain antigravity head and trunk postures and control leg and arm movements.

N°	Item
1	Going up and down stairs without holding onto the banister
2	Running correctly even if you have to turn
3	Going up an escalator alone
4	Walking while holding a fragile object (such as a full glass)
5	Walking several minutes at the same speed as a healthy child
6	Walking backwards
7	Going down stairs putting each foot on the next step
8	Going up stairs putting each foot on the next step
9	Turning and walking in a narrow space
10	Walking less than 5 metres, indoors, holding onto pieces of furniture

The most widely used classifications are based on the work of Winter et al. [10], Sutherland and Davids [11] and Rodda and Graham [12]. These classifications try providing a management framework by giving some recommendations regarding the therapeutic strategies (see Chapter 18).

When a more precise description of the patient is needed, other scales, based on an overall score, can be used. These scales are often presented as an alternative to complex,

expensive and time consuming quantitative gait assessments [13] such as clinical gait analysis (see Paragraph Clinical gait analysis) since they allow an analysis on multiple joints and planes. Most of them propose assessing ankle, knee and hip functions (e.g., the Physical Rating Scale (PRS) [14], the Salford Gait Tool (SGT) [15]) but can be completed with a pelvis function evaluation (e.g., the Observational Gait Score (OGS) [16]) and a trunk function evaluation (e.g., the Edinburgh Visual Gait Score (EVGS) [17]).

The items evaluated by these scales can be defined as representative items linked to a key feature of the CP gait (e.g., knee extension in terminal swing, peak hip extension in stance), or to a key event of gait (e.g., initial contact, toe off). Since these scores are directly linked to the experience and professional background of the operator, results are often presented as inter-observer dependant [18, 19]. Trainings are thus recommended in order to be sure that each operator will evaluate in a similar manner the different items composing these scales.

Focus on the Clinical Video Analysis

The use of video is essential in the clinical analysis of gait. The advantages of this tool are numerous due to its simplicity. First, it allows showing as many times as needed the patient gait and to generate still images or slow motion videos to ease the clinical interpretation. Second, it can be used, as discussed previously, as a reliable tool to fill observation-based scales, even if the patient is present. And last but not least, it can give access, under a strict and standardised protocol, to the computation of some spatiotemporal (e.g., step length) and kinematics (e.g., pelvis tilt, hip/knee/ankle flexion) parameters in the recorded planes (commonly sagittal and frontal planes) (Figure 4) or to the comparison of different gait conditions.
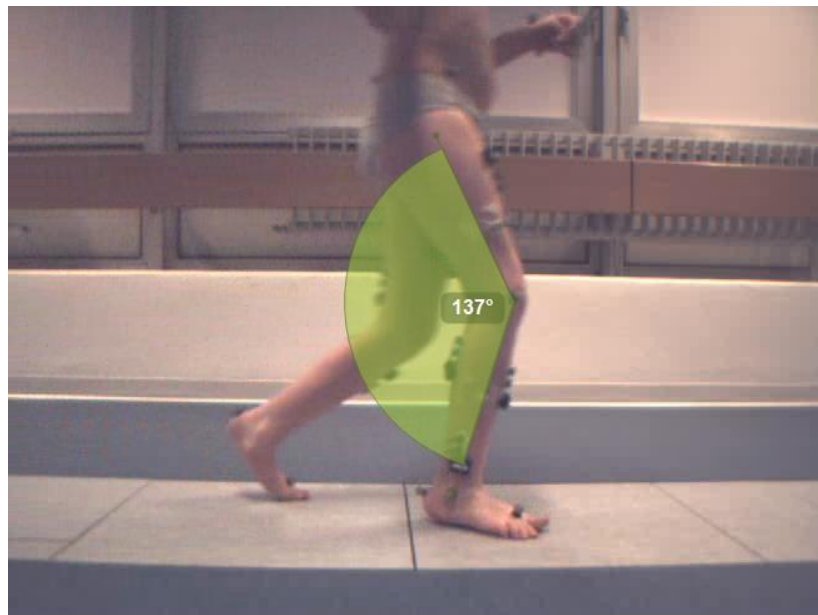

Figure 4. Estimation of the sagittal angulation of knee during gait using the software Kinovea.

17.3. QUANTITATIVE GAIT ANALYSIS

Emergence of evidence-based medicine promotes nowadays the development and use of tools allowing the quantitative assessment of gait. On one hand, such a methodology gives access to the comparison with normative data or between different conditions (e.g., pre- versus post-surgery or treatment) and statistical analysis. On the other hand, the associated protocols must be rigorously respected to ensure the comparison between data and can be time-consuming. Regarding the exponential development of many kinds of sensors, a lot of biomechanical parameters are now available (e.g., kinematics, kinetics, muscular activity, plantar pressure, energy expenditure). But even if technology is becoming omnipresent, fast and reliable clinical tests remain often used and allow a first level of qualitative gait assessment.

Table 2. Edinburgh Visual Gait Score items [17]

Initial contact
Foot rotation
Hindfoot varus/valgus
Knee extension in terminal swing
Max ankle dorsiflexion in stance
Heel lift
Pelvic rotation in midstance
Max ankle dorsiflexion in swing
Peak hip extension in stance
Knee progression angle
Peak knee extension in stance
Peak knee flexion in swing
Peak sagittal trunk position
Max lateral shift of trunk
Max pelvic obliquity in midstance
Peak hip flexion in swing
Clearance in swing

Spatiotemporal Parameters

Spatiotemporal parameters aim describing gait using global spatial and temporal metrics. Their definitions are based on the temporal segmentation of the gait cycle, between two consecutive contacts between the foot and the floor. Indeed, it is common to describe a gait cycle or a stride as a succession of a stance phase (near 60% of the gait cycle), during which the foot is in contact with the floor, and a swing phase (near 40% of the gait cycle), during which the foot moves forward. Of course, a more precise segmentation of the gait cycle is possible (see Chapter 5.1) (Figure 1).

Table 3. Comparison of the common technologies used to measure spatiotemporal gait parameters

Devices	Gait cycle duration	Gait velocity	Step length	Cadence	Gait cycle phases	Precision	Cost
Chronometer	x	*				+	+
Pedometer				x		+	+
GPS	x	x				++	++
Radar speed		x				+++	++++
Cross line detector	x					+++	++
Inertial measurement unit	x	x	x	x	x	++	+++
Footswitch	x	*		x	x	+++	++
Instrumented walkway	x	x	x	x	x	+++	++++
Optoelectronic cameras	x	x	x	x	x	++++	+++++

* On a normalised walkway with a defined distance

The most common spatiotemporal parameters are the gait velocity, the step length (i.e., the distance between the ipsilateral foot strike and the following controlateral foot strike), and the cadence (i.e., the number of steps per minute). These parameters present a reduced variation in healthy people walking on a straight level floor, but may vary depending on the environment (e.g., turn, obstacle, stairs). Normative data of these parameters have been made available [20].

Other parameters may also be calculated. Stride length (i.e., the distance between two consecutive ipsilateral foot strikes) and stride width complete the spatial parameters while the duration (in seconds or expressed in percent of gait cycle) of the right and left stance phases, swing phases and double support phases provide more details about the temporal segmentation of the gait cycle.

When the patient suffers of any locomotor trouble, all these parameters are often affected and thus point out the alteration of the normal gait cycle. For example, a hemiparesis may modify the symmetry of the right and left parameters.

More generally, instability, muscle weakness or spasticity may reduce the gait velocity to ensure a secured gait. Thus, these parameters give to the clinician first level indicators during the assessment of the patient.

Basically, a chronometer is enough to catch a set of these parameters and different basic clinical tests have thus been developed. Gait velocity and cadence can be measured through the 10-meter walk test, gait perimeter through the 6-min walk test and the initiation of walking and direction change through the Timed Up and Go test [21].

But even if some spatiotemporal parameters can be deduced from these clinical tests, sensors are often required to record a more complete set of these parameters. Different technologies can be used to measure them, such as instrumented walkway, video cameras, optoelectronic cameras, accelerometers or footswitches. The most common technologies are listed and compared in Table 3. Anyway, a great interest of spatiotemporal parameters is that evaluation can be done on different floors and conditions and thus allows an overview of the patient capacity in some ecological situations.

Kinematics

Kinematics aims describing the angular variations of the joints (i.e., the joint angles) composing the lower limb during a movement.

For that, the position and orientation in space of each bony segment during the performed movement are required. Typically, for a 3D analysis, each segment is defined through the position of a minimum of three landmarks allowing the definition of the three axes (i.e., antero-posterior, proximal-distal, medio-lateral axes) composing the segmental coordinate system (SCS) (Figure 5).

The position and orientation variations operated by these SCS allow then describing the rotations and translations of each segment in the inertial coordinate system (ICS) (i.e., the coordinate system of the laboratory) or in the SCS of another segment.

Finally, the joint angles can be obtained through the difference of the rotations and translations of two consecutive segments. Commonly, the results of such an analysis provide the pelvis orientation in the ICS (i.e., pelvis tilt, obliquity and rotation), the flexion/extension, abduction/adduction and internal/external rotation at each joint (i.e., hip, knee and ankle) and the rotation of the foot in the ICS (i.e., also known as the foot progression angle) (Figure 6).
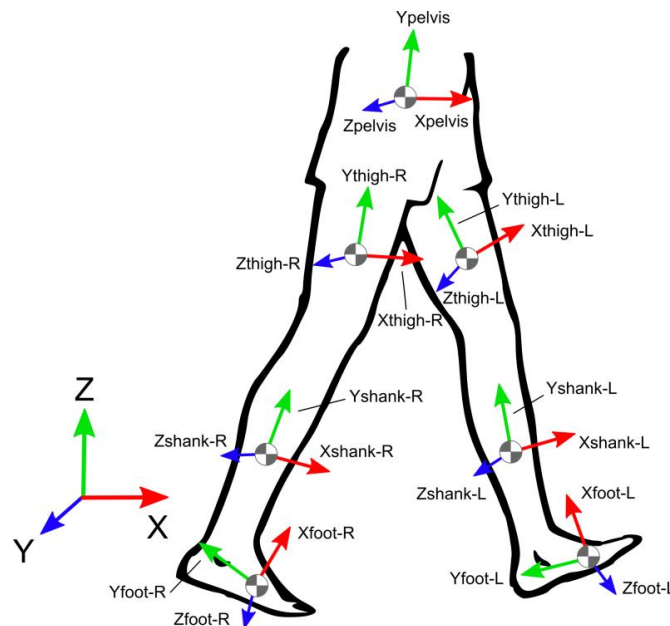

Figure 5. Inertial and segmental coordinate systems.

Biomechanical Models and Computation of Joint Angles

The biomechanical models aim defining the hierarchy of the bony segments, their anthropometry and the type and number of degrees of freedom of the joints linking them. Commonly, these models consider the segments as rigid and thus do not take into account the potential deformations due to the different type of structures composing these segments (e.g., muscles, ligaments, menisci).
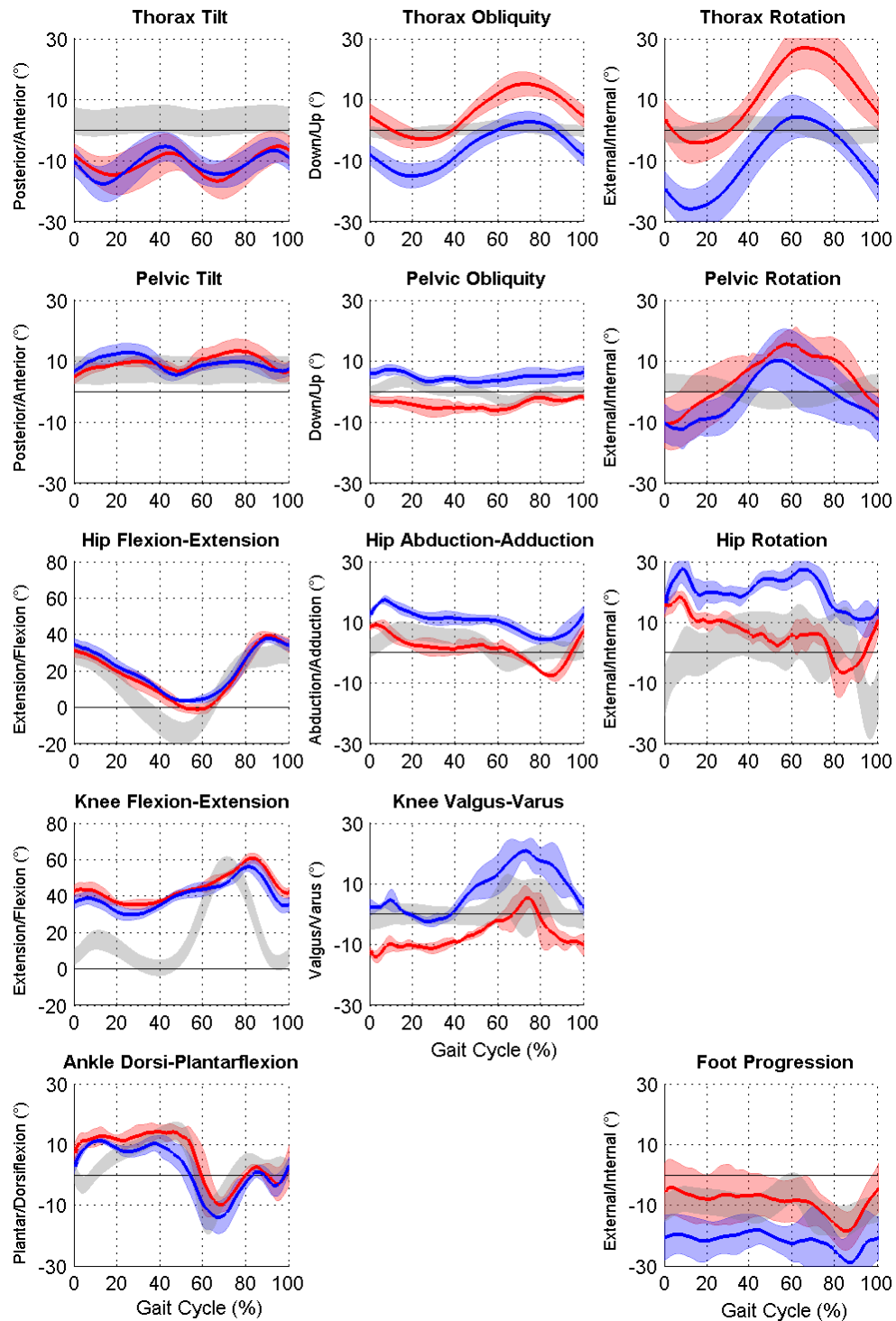
Figure 6. Typical kinematic results obtained during a clinical gait analysis (Red – left side, blue – right side, grey area – normal values).

While anthropometry can be easily obtained from physical measurements (e.g., weight, height, leg length), the position and orientation of the segments, as introduced previously, require a mathematical framework for their computation.

The way the joint angles are calculated is also part of the definition of the biomechanical models. For example, the way the different axes of a SCS are described depends on the chosen model.

In order to normalise data and to ease data exchange and scientific collaboration, the International Society of Biomechanics (ISB) submitted a set a recommendations for the definition of the SCS of both upper and lower limb segments [22]. Once again, the way the joint angles are computed depends of the model. Traditionally, the Euler method is used (but other methods exist such as quaternions, helicoidal axis or homogeneous matrix) and requires the selection of the axes sequence to reduce numerical errors during angles computation. The ISB recommendations also suggest a set of axes sequence to normalise the way the angles are obtained.

However, recording devices, presented in the next paragraph, often promotes other models (e.g., Vicon system: Plug in gait model, Motion Analysis system: Helen Hayes model, Qualisys system: Leardini model) making then difficult the comparison between records. Softwares (e.g., C-Motion, Mokka) and open-source packages (e.g., Biomechanical Tool Kit) help overcoming these limitations [23].

Recording Devices

In order to compute kinematics, segment positions and orientations are needed. Different types of recording devices exist (Table 4). While multiaxial goniometers may allow a first level of precision for a 2D analysis, optoelectronic systems are nowadays the most common systems for clinical gait analysis.

Basically, the goal of these systems is to identify the 2D or 3D position in space of a set of cutaneous markers placed on each segment. These markers can be passive (i.e., without inherent identity – the user must identify them manually or semi-manually) or active (i.e., each marker send a specific signal to the cameras giving them its identity). In order to define SCS, these cutaneous markers are placed at some specific landmarks.

Most of the time, in order to increase repeatability and precision, a set of bony landmarks is chosen for each segment (e.g., anterior and posterior superior iliac spines, femur epicondyles, malleolus) (Figure 7).

When a gait analysis is required in real conditions (i.e., out of a gait laboratory), optoelectronic systems are though not well adapted due to high light reflections and system installation time. In that case, inertial measurement units (IMU) are preferable. These systems combine a set of sensors such as accelerometers, gyrometers, magnetometers that can be uni-, bi- or tri-axial, depending on the need. Instead of optoelectronic systems, IMUs have inherent SCS (i.e., the axis of the sensors).

Table 4 compares this kind of system with other type of systems. In most of the cases, these systems required a calibration before records and a dedicated time may thus be defined.

Table 4. Comparison of the common technologies used to measure kinematics

| Devices	Main manufacturers	Main advantages	Main drawbacks	Cost
Electronic goniometer	Penny and Gilles	Easy use	2D measurement Precision	+
Inertial measurement unit	Xsens technology McRoberts GaitUp APDM movement monitor solution Techno-Concept	3D measurement Portable Direct measurement	Deriving signal	++
Electromagnetics	Polhemus	3D measurement Precision	Ferromagnetic interferences	++
Optoelectronic with passive markers	Vicon Motion Analysis Qualisys Optitrack BTS	3D measurement Precision	Sensitive to light reflections	+++
Optoelectronic with active markers	Codamotion Optotrak Qualisys	3D measurement Precision	Wiring	+++
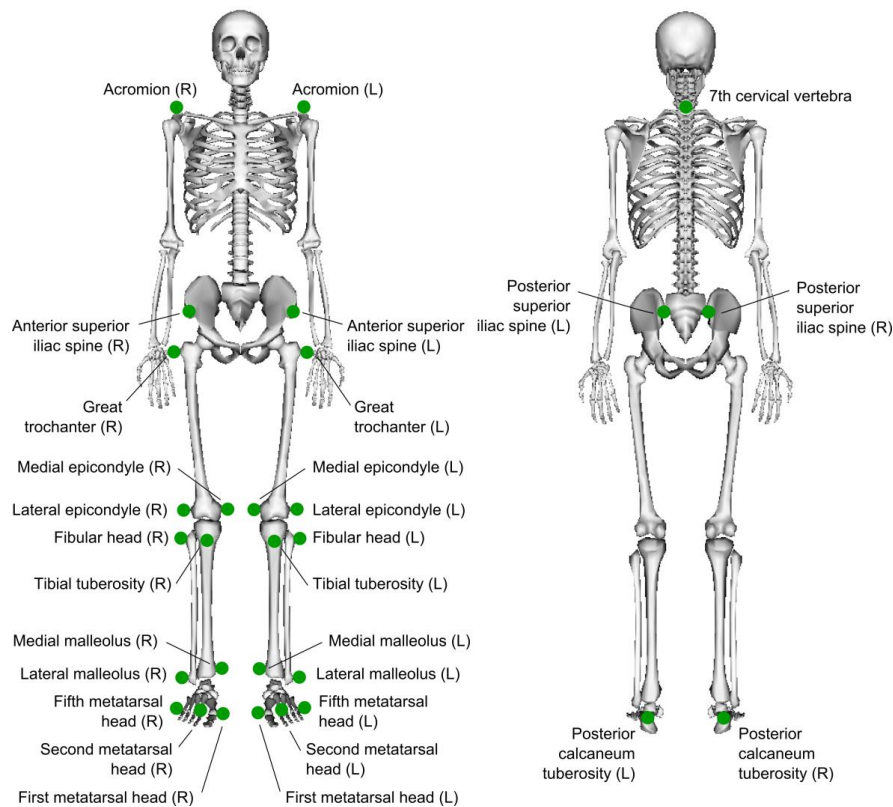
Figure 7. Example of a set of landmarks used to describe lower limb bony segments during gait.

Drawbacks

The most important drawback is based on the fact that, whatever the system used, the position and orientation of the bony segments are obtained by placing a set of sensors on the skin. However, soft tissues like skin and muscles can move on the underlying bony segment during a movement. Consequently, the records are altered by these artefacts reducing the precision of the measurements [24]. A special attention is thus required to select landmarks reducing these artefacts and additional markers may be advocated to correct mathematically this measurement noise.

Kinetics

Kinetics completes kinematics by introducing external forces and moments acting on the model previously described to explore the joints forces and moments. During gait, these external forces and moments are commonly composed of the weight and the ground reaction forces (see Chapter 16). Notice that in case of use of a walker, simple or tripod canes, other external forces and moments have to be introduced. Traditionally, the inverse dynamics method is used to compute joints forces and moments. This method allows calculating the net joints forces and moments (i.e., the sum of motor and passive forces and moments). Furthermore, based on kinematics and kinetics, joints powers can be computed as the product of angular velocities and joint moments.

External Forces and Moments

On the one hand, ground reaction forces are commonly measured using forceplates recording net forces and moments acting between foot and floor. Even if forceplates provide straightforwardly forces and moments, measurement data can only be interpreted if only one foot is in contact with a forceplate and only in contact with this forceplate (not with surrounding floor). On the other hand, the weight acting on each segment cannot be directly recorded. For that, it is common to use regression tables [25, 26] defining inertial parameters (i.e., mass, segment centre of mass location and inertial matrix) based on a set of anthropometric measurements (e.g., gender, weight, height). These regression tables can be based on cadaveric measurements or medical imaging data. Notice that different regression tables exist and users must insure selecting a table corresponding to the evaluated population. In the case of children, the regression table proposed by Jensen [27] can be used.

Lower Limb Joints Moments and Power

Once external forces and moments have been applied on the kinematic model using for example the inverse dynamics method, joints forces, moments and power can be analysed. Commonly, for a clinical diagnosis, lower limb joints moments and power are used. Figure 8 gives results for ankle, knee and hip in the sagittal plane and compares normal and CP gait.
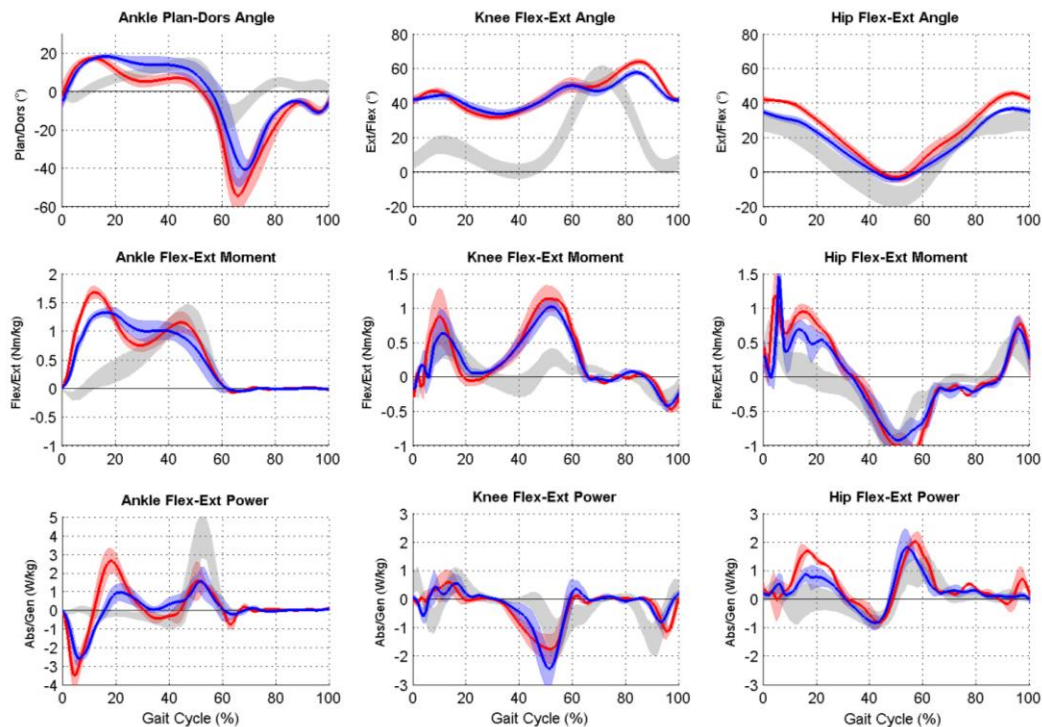
Figure 8. Typical kinetic results in the sagittal plane obtained during a clinical gait analysis.

Dynamic Electromyography

While kinematics completed by kinetics gives information about how segments move, the contribution of each individual musculo-tendon force to the joint motor moments is not accessible. However, this information is clinically essential to understand motor control. A first level of information can be obtained by using dynamic electromyography (EMG). By synchronising a set of EMG sensors signal to the kinematic and kinetic data, the temporal activity of the recorded muscles can be linked to the joints angle variations and moments.

Record Surface and Deep Muscular Activity

The EMG signal corresponds to the sum of the potential of action of the motor units in the field of the EMG electrodes. Cutaneous electrodes are used for surface muscles, while finewires are required to record the electrical activity of deep muscles. In both cases, the quality of the signal is highly influenced by the electrode location. Some recommendations exist and provide a normalised and repeatable set of locations (e.g., the European research project SENIAM - Surface EMG for Non-Invasive Assessment of Muscles, http://www.seniam.org/).

About the Recorded Signal

Once the electrodes or finewires have been correctly located of the limbs, the EMG signal can be recorded during the explored movement (e.g., gait). However, the raw signal

can not be directly used for clinical diagnosis. Indeed, mathematical treatments are required to correct the signal of environmental and technical noises.

Typically, the EMG signal can be contaminated by the 50Hz electrical signal coming from the power supply or by the movements of wires or sensors composing the measurement device. Some filters are thus necessary to get a signal only composed of the muscular electrical activity (Figure 9). Then, the signal can be smoothed in order to obtain the EMG envelop, facilitating the understanding of the signal (Figure 9).

Finally, a last mathematical treatment may be applied in order to keep only the temporal information of active/non-active periods of each recorded muscle (i.e., EMG onsets).

But even if the correct mathematical treatment has been applied, the user must always keep in mind that the use of surface EMG may record not only the desired muscle activity, but also the activity of surrounding muscles (e.g., the measurement of the rectus femoris activity is often contaminated by the vastus intermedius electrical signal). This kind of artefact is called crosstalk.
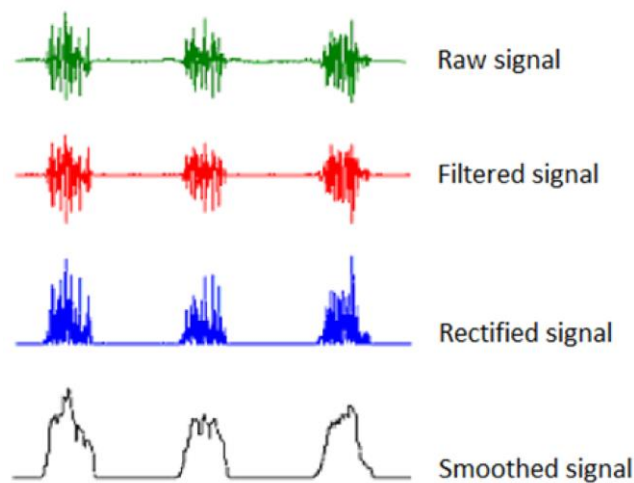

Figure 9. Common treatment steps applied on raw EMG signals.

Other Outcomes

Musculoskeletal Modeling

Musculoskeletal models have emerged these last 20 years [28]. One application of these models is to complete the inverse dynamics method by a set of muscular lines of action. Through the use of mathematical methods such as optimisation, it is then possible to investigate the contribution of each individual musculo-tendon force to the joint motor moments or to compute muscle length and stretch velocity. Another application is to simulate a treatment or a surgery to predict the potential results on gait. It must be noticed that the validation of these models is not trivial and that their use should be currently limited to understand a phenomenon and not to get precise results.

Plantar Pressures

Plantar pressures measurements permit to assess pressures distribution (Figure 10) and foot rockers. It is thus an efficient tool to understand the way the foot is in contact with the floor during all the stance phase. Basically, two kinds of device are commonly used to measure foot pressures. On the one hand, insoles allow analysing the interaction between the foot and the shoe during gait.

For example, it can allow defining and adjusting the use of orthopaedic insoles. On the other hand, pressure plates allow exploring the interaction between barefoot and floor.

Energy Expenditure

More global activity measurements are also available to evaluate human gait such as energy expenditure or physical activity. Through the use of GPS, accelerometers, pedometers or heart rate monitors, a global physical activity can be estimated during gait in some different conditions and basically during daily life. More specifically, indirect calorimeters can be used on a treadmill to measure oxygen consumption, metabolic equivalent or respiratory exchange ratio.
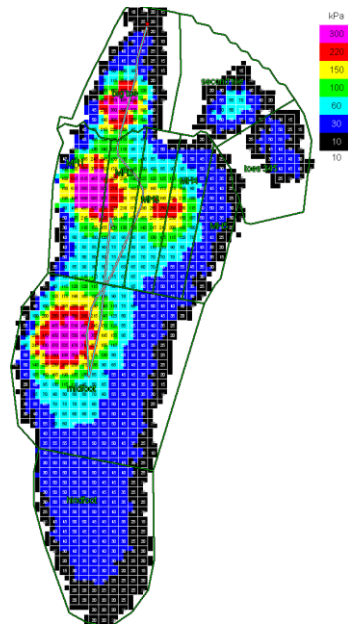

Figure 10. Sum of the pressure distributions during a gait cycle obtained with a Novel plantar pressure mat.

Merged Measurements and Summary Indexes

In the last decades, it has become common to record gait parameters, kinematics, kinetics and dynamic electromyography during a single exam called clinical gait analysis (CGA). Indeed, thanks to the current technologies, these parameters can be recorded simultaneously and synchronised. CGA is discussed in details in "Clinical gait analysis".

CGA can give access to a high number of parameters and it can be challenging to interpret everything and to compare data. Thus, the volume of these parameters can be an obstacle for a clinical use. In order to summarise the results, several indexes have been proposed. The aim is then to merge a set of selected parameters to provide a concise value reflecting for example the degree of gait deviation.

The most common indexes are the normalcy index (NI) or Gillette gait index (GGI) [29], the gait deviation index (GDI) [30], the gait profile score (GPS) and the movement analysis profile (MAP) [31]. Most of the time, these indexes are based on spatiotemporal and kinematic parameters, while a GDI-kinetic have been proposed [32].

But even if these indexes can be convenient for a clinical use, it must be noticed that by giving a global gait level, impairments at a joint or on a plane can be masked and the results of a treatment can thus not be visible (i.e., the index may not be sensitive enough to the introduced gait modifications).

17.4. CLINICAL GAIT ANALYSIS

Process

The process of analysis gait disorders is generally based on the identification, understanding and treatment of gait deviations according numerous scientific and medical knowledge and resources (Figure 1). Currently, the most advanced assessment to analysis gait disorders is CGA that is an instrumented measurement of the movement patterns of a person during walking. The core of this analysis consists of the measurement of joint kinematics and kinetics in three dimensions. Moreover, CGA generally includes video recording and electromyography assessment [33]. Moreover, some laboratories propose measuring plantar pressures and/or energy expenditure during walking [34]. CGA provides an objective record that can quantify the magnitude of deviations of pathologic gait from normal and also permits understanding these abnormalities [35] with the finality to support clinical decision. Other aims could be evaluating therapeutic effects or following gait evolution of a patient gait. Patients are addressed to the laboratories on medical prescriptions that will provide the medical history, the examination aims, the specific elements to investigate and sometimes the expected therapeutic solutions. The report of the examination includes different scores (e.g., GPS, GDI, MAP, etc.), spatio-temporal results (e.g., walking speed, cadence, step length, duration of stance phase), kinematics and kinetics (presented with graphics for each joint/segments and each plan - sagittal, frontal, transverse - for the left and right sides). All the graphs are normalized against the gait cycle and expressed in percentage (Figure 11). Graphs include also normative data (mean +/- one standard deviation) to permit identifying gait deviations. EMG can also be presented as raw data and/or as the envelop of the signal.
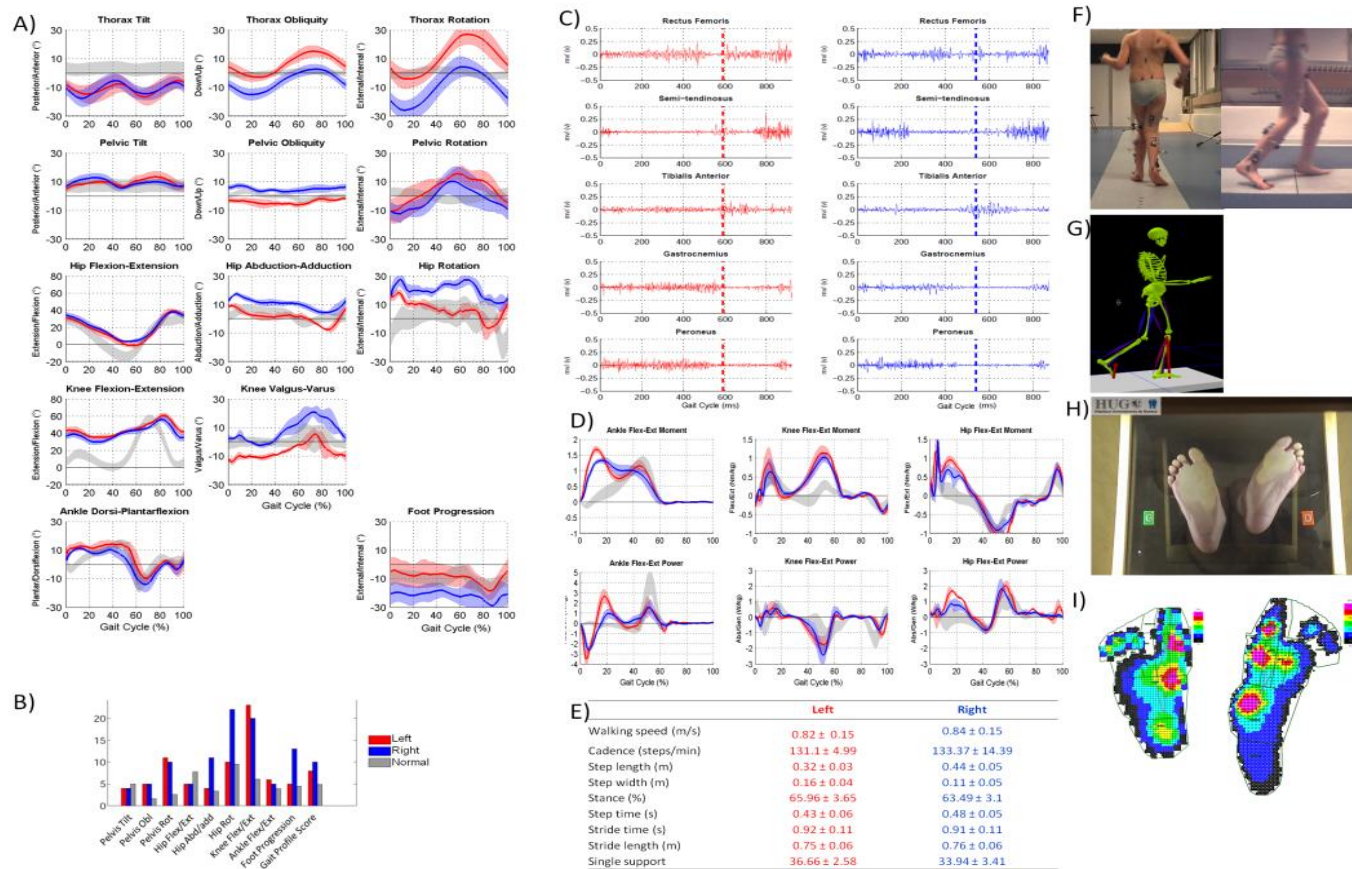
Figure 11. Example of data in clinical gait analysis report: A) Kinematics, B) Gait scores, C) EMG, D) Kinetics, E) spatiotemporal parameters, F) Video, G) 3D animation, H) Podoscope, I) Plantar Pressure

Once the gait deviations have been identified, gait deviations must be understood. This task requires establishing the links between several types of data from CGA (e.g., kinematics and EMG) but also from medical practices such as physical examination, medical history, imagery, complementary examination [36]. The physical examination consists to assess anthropometry, range of motion [37], muscular strength [38], selectivity [39], spasticity [40, 41] and pain. In parallel, medical imagery is often an important resource to assess bone deformities and muscle impairments. The interpretation task of CGA requires a multidisciplinary team with knowledge on clinical gait analysis. Knowledge of reference books [20, 42-47] is necessary as well as regular updates with scientific literature and congress (e.g., GCMA, ESMAC) to be able to perform fine interpretation of gait disorders. The success of interpretation will depend on the experience of the team.

It must be noticed that CGA have some limitations that the team must keep in mind during the interpretation of the results:

- the accuracy of measurement devices that is around 1 mm and 1.5° for the kinematics [48, 49],
- the variability of the examiners during the installation of the sensors [50-52];
- the soft tissue artifact (relative movement between the markers and the underlying bone due to skin deformation and movement, muscle contraction, inertia effects of soft tissues) [24],
- the difficulty of biomechanical models to represent the clinical impairments (e.g. midfoot break with a single segment model of the foot),
- the technical walking aids needed for some patients that make the interpretation of results more difficult.

Clinical Relevance

A large variety of gait deviations can be observed in CP patients (see Chapter 18). From these patterns, it is important to distinguish the primary gait deviations which are a direct consequence of the underlying deficits associated with the pathology, and the compensatory strategies which are the deviations due to the biomechanics constraints of the primary gait deviations [53]. Only the primary deficits are the target of treatments [54]. Indeed, the compensatory strategies should disappear once the primary deficits are addressed. Understanding gait deviations is not straightforward due to the highly complex nature of the human neuro-musculo-skeletal system and the dynamic nature of walking. However, understanding gait deviations is of primary importance to optimize the treatment strategies for patients presenting abnormalities. Numerous studies have shown the benefits of using CGA to optimize treatment strategies in complex gait disorders, mainly in cerebral palsy children.

The benefits of CGA are:

- A more accurate assessment of gait deviations than using a single 2D video [55, 56],
- A better prescription of treatments: with a modification and reduction of the number of treatments [57-63],
- More effective treatments in cerebral palsy [64],

- Cost-benefit and cost-effectiveness are improved if the treatments are determined with CGA [65],
- An excellent assessment of the effect of treatment [35].

In addition to its clinical relevances, CGA has an educational role. Its use provides the opportunity to learn and analyze complex movement disorders. The clinicians using CGA will subsequently have a better understanding of movement disorders even without considering CGA data. The post-treatment CGA evaluation can also provide an excellent feedback for clinicians who can learn from the successes and mistakes of the treatments used [66]. Moreover, CGA allows an objective long-term longitudinal follow-up of the patient's gait. Although the therapeutic contribution of CGA is undeniable [66], this clinical examination suffers from a lack of recognition in some institutions. Indeed, it is certainly linked to the difficulty of having a completely standardized examination between laboratories, the difficulty of analyzing a complex dynamic phenomenon with many interacting variables and misinterpretation of the role of the examination in some cases. In fact, studies have shown variability between results obtained from the therapeutic recommendations resulting from CGA [67, 68]. However, the same variability has been found in therapeutic recommendations from other medical imaging examinations. For example, using the same X-ray images, treatment decisions can vary from one clinician to another for the treatment of scoliosis [69]. Despite these difficulties, CGA helps identifying and understanding gait deviations. We can speculate that a better understanding of gait deviations can lead to better treatment choices, but the final choice of treatment strategy depends upon the medical team (e.g., availability of the treatment, experience in the treatment procedure, knowledge of the medical history of the patient) and different context information as illustrated by the ICF (Figure 2).

CONCLUSION

To deal with gait disorders, it is essential for the clinician to characterize and understand the altered gait to support the therapeutic choice. Numerous complementary tools are available to assess gait disorders. Currently, clinical gait analysis, including the objective assessment of numerous gait parameters in laboratory setting, is the most advanced examination to identify gait deviations. However, this important information about the capacity of a patient to walk in ideal conditions should be completed with assessment in real life condition. The ICF provides a good framework to choice different tools assessing the different domains and have a general overview on gait disorders, their consequences and their causes. In the near future, we can expect that objective assessment in real life (such as using inertial sensors), more advanced body structure evaluations (such as fusion between imagery and kinematics), more advanced techniques linking gait disorders and possible causes (such as data mining) will be used to complete information from clinical gait analysis to better support the therapeutic choice.

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