

Normal walking

Principles, basic concepts, terminology

3-dimensional clinical gait analysis

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SUMMARY

Bipedal walking is a defining human characteristic requiring anatomical integrity and normal function of the nervous and the musculoskeletal system. Disorders affecting any level of this complex mechanism will lead to abnormal gait disturbances. Clinical assessment of gait pathology, on the other hand, implies detailed knowledge on normal gait function. Investigations to gain insight into normal walking started with the studies of Aristotel (384 BC) on the locomotion of animals followed by others in the centuries to come. Contemporary methodology on evaluating normal gait is based on the contribution of Inmann, Saunders, Sutherland, J. Perry, Gage and others from the early 50's until now days. With the introduction of instrumented gait observation they were capable to record and describe the gait movement. By applying the principles of biomechanics on locomotion they defined and measured different parameters (speed, stride length, force etc) introducing the gait terminology. Thus the gait cycle, that corresponds to a single stride, was established as a functional unit of normal walking. Every gait cycle is divided in two consecutive phases: stance (weight bearing) of one leg followed by swing of the same leg. Each phase is

then further divided into a number of different periods. Their duration is expressed as percentage of the gait cycle. This configuration made possible the objective description of walking and the measurement of a variety of parameters at every desired time interval of the gait cycle. Gait assessment is performed in Gait Laboratories using video, PC, force plates, EMG and applying special software, in a procedure which is called 3-Dimensional Clinical Gait Analysis. Following a systemic methodology normal walking is recorded, displayed and validated quantitatively in the sagittal, frontal and transverse plane (3-D). Gait disturbances due to movement disorders can be captured measured and evaluated in comparison to normal gait patterns in order to assess the walking abilities of the patient. Gait Analysis includes Clinical Examination (medical history, clinical observation and examination etc), Kinematics Analysis, Kinetics Analysis and dynamic EMG. Kinematics refers mainly to joint, trunk and pelvis displacement trajectories, without consideration for the cause and the forces involved. Measurements are displayed in a Cartesian coordinate system diagram, where the x-axis represents time intervals expressed in percentage of the gait cycle and the y-axis joint displacements expressed in angle grades. Kinetics includes measurements of forces, both internal (produced mainly by muscle activity) and external (produced by gravity or external loads), measurements of moments across joints and work production, that cause movement. These measurements are expressed in N (Newton), Nm (Newtonmeter) and W (Watt) on

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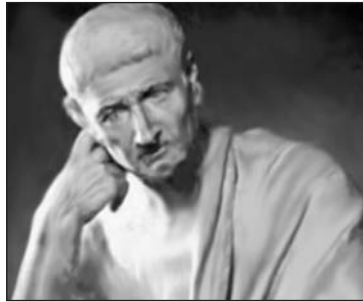


Figure 1. Aristotel (384-322 BC).

the y-axis, while the the x-axis represents again time intervals of the gait cycle. In EMG Analysis muscle activity during gait is measured in mv or uv and displayed on the y-axis. At the end of the 3D Clinical Gait Analysis we are informed, in the form of diagrams and numerical quantities, about the range of motion of the joints and their abnormal deviations, the moment and work production across the joints, the functional level of the muscles involved. All data together with the clinical examination and medical history are included in the gait analysis report, where the relationships between functional deviations and gait disability are interpreted ; thus facilitating the creation of a treatment plan and a rehabilitation program to enhance walking performance of the patient and the communication between the members of the treating team as well.

INTRODUCTION

Human body is designed to move. Gait is a type of bipedal movement, with innate instability, where a sequence of rhythmically repeated, alternating movements of the trunk, the upper limbs, the pelvis and the legs leads to forward locomotion (forward progression of the center of gravity).

Gait is a complex activity that requires a control system (nervous system), motor generators (muscles) to produce power and moments, a system of levers (bones) to transmit motion. Disturbances in any segment of these kinetic mechanisms restricting normal joint range of motion or altering normal lever morphology or interfering with the timing of muscle activation, will create deviations of the normal gait pattern.

It is obvious that the pathogenesis of gait disorders is multifactorial while evaluating gait disturbances implies in depth understanding of normal walking mechanisms.

Aristotel (384-322 BC) was the first to study human and animal locomotion in his work "On animal locomotion"^{1,2}.

Giovanni Borelli (1608 AC), Italian mathematician, medic and physiologist created models of human and animal bodies in the form of a lever system; by studying forces acting during motion introduced the methodology of contemporary biomechanics².

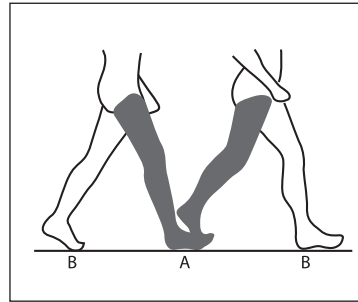


Figure 2. Phases of double support.

The French E.J. Marey (1870) and the American E. Muybridge (1880) performed gait assessment using multiple camera technology^{2,3}.

In 1945 Inmann and his coworkers initiated the instrumented data collection and the application of biomechanical principles for gait evaluation thus introducing modern gait analysis⁴.

In the following years the contributions of Saunders et al (1953), Sutherland (1988),

J. Perry (1992), J. Gage (1991) and others have increased our understanding on gait mechanisms and established modern gait terminology^{5,6,7}.

THE CLINICAL SIGNIFICANCE OF NORMAL GAIT STUDY

Until recently normal gait study and gait problems assessment, especially in neurologically impaired persons, was empirical based on observation of gait and clinical evaluation. However, the employment of modern motion capture technology with movement measuring capacities, made the approach of gait disorders possible, on a more scientific level, by calculating joint range of motion, forces and moments across joints and other parameters^{3,8}.

Knowledge of basic normal gait principles and gait terminology based on instrumented measurements enhance the assessment accuracy of gait capabilities and the potential to differentiate between gait pathologies. The wide acceptance of this common methodology facilitates the interaction between the treating personnel and the creation of an optimal treatment plan⁹.

NORMAL GAIT

Walk = to move or go somewhere (Oxford Advanced Learner's Dictionary, 2000).

Neonates are dependent because they lack the capability of locomotion (moving in a specific direction). Bipedal walking is a dexterity gained by the 11th month¹⁰.

Bipedal walking

Humans use bipedal upright gait. Unlike quadruped locomotion bipedalism is inherently unstable, because the trunk and the appendicular skeleton are located above the

pelvis and the legs. This makes the center of mass, located in front of the second sacral vertebra, top heavy. In the upright position the center of mass must be

kept over a narrow base of support. During walking the different segments of the legs are changing constantly their position making it necessary for the trunk to balance above a moving base of support^{4,9}.

On the other hand bipedalism is more energy efficient. In 2007 American scientists comparing energy consumption in humans and chimpanzees noted that human bipedalism is 4 times less energy consuming¹¹.

In bipedal gait the hands are no more implicated in locomotion remaining available for more significant uses.

Gait is a bipedal locomotion where one leg (A) is landing while the other (B) is still on the ground, it includes a phase of double support.

At this moment the body weight is transferred from the supporting leg (B) to the opposite leg (A) that is landing. For the rest of the gait one leg supports the body while the other swings. During a gait cycle two phases of double support exist namely at the beginning and at the end of stance.

Unlike running, in bipedal walking there is no time moment during leg reciprocation that both legs are not touching the ground^{4,12,13}.

THE GAIT CYCLE

Gait is a sequence of consecutive, uniformly repeated locomotion events in space and time, in other words it is a movement repeated in defined time intervals.

Gait is a periodic movement (cyclic)^{4,7,9,10}.

The cyclic repetitive character of gait led to the idea of introducing the time interval of a gait period or a gait cycle as a functional unit for the study of different parameters in gait. A gait cycle is defined as the time interval between two identical movement events during gait. Any event can be used as starting point of a gait cycle because the events follow each other in a consecutive, uniform manner. The heel contact to the floor (heel strike) is widely accepted as the starting point and the next contact of the same heel as the end of a gait cycle.

A gait cycle includes a start, an intermediate period and an end. It is divided in consecutive phases and periods measured in percent of the gait cycle for each limb separately.

The gait cycle is divided in a stance phase lasting 65% of the cycle and a next swing phase of the same leg lasting 35% of the cycle.

Stance starts when the heel contacts the ground (0% of the cycle), lasts as long as the sole of the foot contacts the floor and ends at the moment when the toes are leaving the ground (65% of the cycle).

Swing starts when fingers leave the ground, lasts as long as the leg swings and ends when the heel touches the ground again (100% of the cycle).

In order to avoid a fall when the reference leg is lifted (end of stance) and starts to swing, a period of double support is interposed, occurring at the beginning and at the end of stance phase lasting 15% of the gait cycle.

The first period of double support occurs when the heel of the reference limb contacts the ground (start of stance) while the contralateral limb is preparing to swing. A single leg stance phase (corresponding to 35% of the gait cycle) follows when the contralateral leg swings.

The second period of double support follows when the reference leg prepares to swing and the heel of the contralateral leg, at the end of the swing phase, touches the floor.

Single leg support phase of the reference limb lasts as long as the swing phase of the contralateral limb (35% of the gait cycle).

In normal bipedal walking symmetry exists between both legs movement, making the gait cycle of both sides identical^{4,14,15}.

In abnormal walking pathological gait patterns exist as in cases of osteoarthritic hip where stance phase of the one leg is shorter because of the painful weight bearing.

PHASES OF THE GAIT CYCLE

The gait cycle is divided in two phases (stance - swing) and eight periods. They must be all included in order for the observed gait to be normal.

Every phase is separated in consecutive periods. Stance comprises five and swing three periods.

A) Stance Phase includes 5 periods:

- 1) initial contact
- 2) loading response
- 3) midstance
- 4) terminal stance
- 5) preswing

B) Swing Phase includes 3 periods:

- 1) initial swing
- 2) midswing
- 3) terminal swing

During a gait cycle the Center of Gravity is displaced vertically in a rhythmical up and down movement along a smooth sinusoidal curve (average displacement 3cm). It reaches the highest point (zenith) at midstance (30% of gait cycle) and the lowest (nadir) at double support (0% & 65%).

The period from zenith to nadir is a phase of acceleration (controlled falling) while from nadir to zenith a phase of deceleration. Forward progression can be described as a series of controlled falls.

1) *initial contact (heel strike)*

Interval: 0%

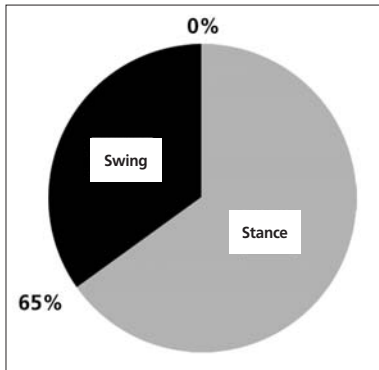


Figure 3. A gait cycle (stance - swing).

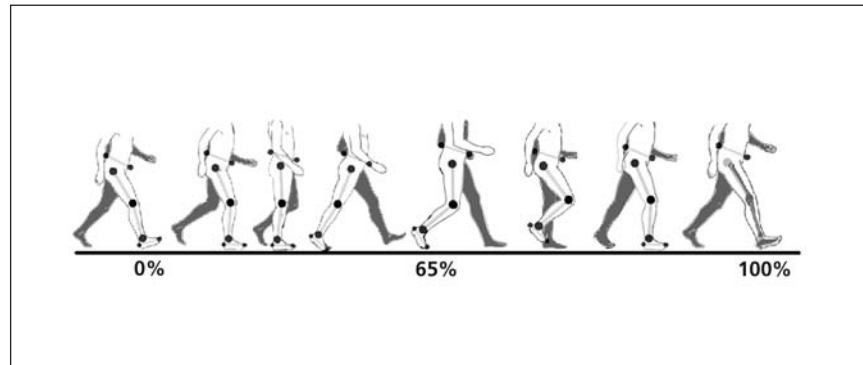


Figure 4. Consecutive phases of a gait cycle

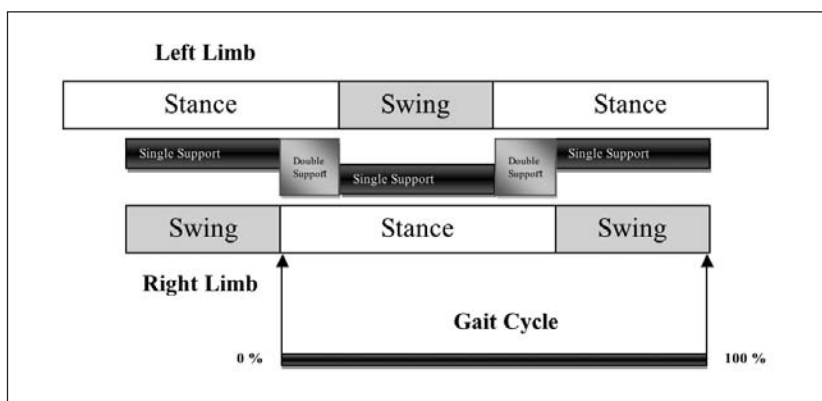


Figure 5. Phases of double and single support in a gait cycle.

limit: Start of 1st Double support
The instantaneous event when the heel just touches the ground (heel strike).

The ankle is in neutral position (0°), the knee in slight flexion (5°), the hip in flexion (35°).

The objective is to prepare the foot for the proper landing position and for the following period of shock absorption of the floor impact.

2) Loading Response

Interval: 10%

limits: End of 1st Double support
Start of one leg support

The period from heel strike until the sole contacts the ground and BW is transferred to the supporting leg (reference leg).

The ankle is in slight plantar flexion ($<10^\circ$), the knee in flexion (15°), the hip in flexion ($<25^\circ$).

The objective is the shock absorption of the floor impact (ground reaction force arises to 130% of body weight) and the preservation of forward progression.

1st rocker

Begins with initial floor contact by the calcaneal tuberosities, acting as a fulcrum around which the foot drops into plantarflexion.

Lasts until the entire sole of the foot contacts the ground¹⁴.

3) Midstance (mid support)

Interval: 30%

Limits: End of the first half of stance
Start of the second half of stance

The period the contralateral leg is lifted while BW is transferred along the sole to the forefoot of the reference leg.

The ankle is in neutral position (0°), the knee almost straight (5°), the hip in neutral position.

Objective is to secure stability of the supporting leg in order to facilitate forward advancement of the swinging leg.

2nd rocker

The tibia is advancing over a stable foot using the ankle as a fulcrum to facilitate forward progression of the body.

Starts when the entire sole contacts the ground and lasts until heel rise begins (end of mid stance)¹⁴.

Starts with heel rise of the reference leg and forward transfer of BW on the metatarsals. Lasts until the contralateral (swinging) leg touches the ground.

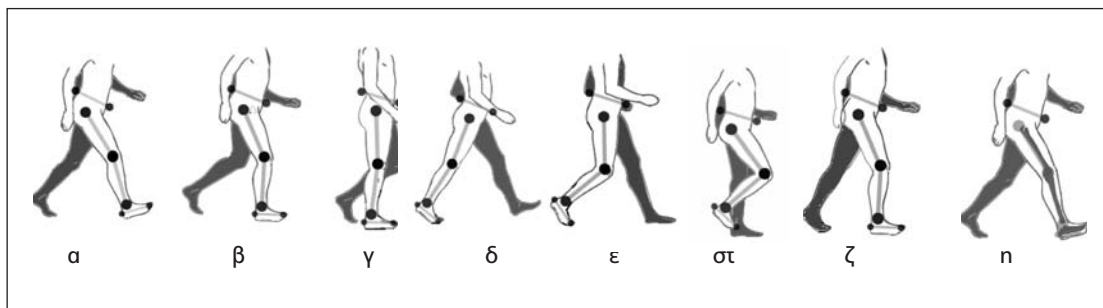


Figure 4.

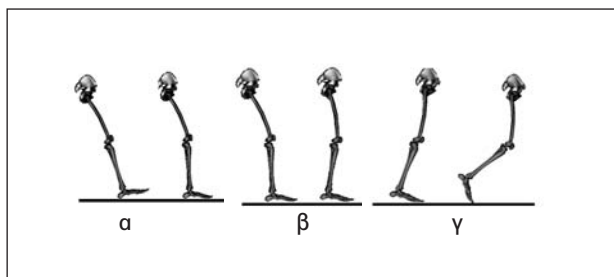


Figure 5.

The metatarsalphalangeal joints are in dorsiflexion (20°), the ankle in neutral position (0°), the knee in flexion (15°), the hip in extension (15°).

Objective is the acceleration produced by the anterior fall of CBW and the contraction of the gastrocnemius muscle.

4) Terminal stance

Interval : 50%

Limits: End of single support
Start of double support

For body progression over the stance limb the essential component is the action of three rockers by the foot and ankle of the reference limb⁷.

3rd rocker

Begins when the heel leaves the ground while BW is transferred forward over the heads of the metatarsals as a fulcrum. Serves as a base for limb acceleration in preswing¹⁴.

5) Preswing

Interval: 65%

Limits: End of double support
Preparing swing

The instantaneous event when the foot of the supporting (ipsilateral) leg is leaving the ground. It determines the end of the phase where BW is transferred from the supporting leg to the contralateral limb allowing the toes of the ipsilateral limb to leave the ground.

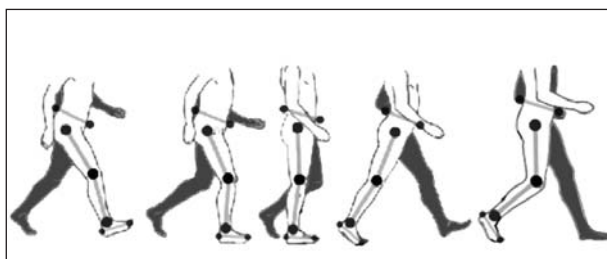


Figure 6. The five consecutive periods of stance.

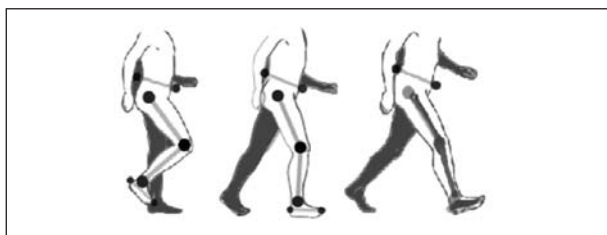


Figure 7. The three consecutive periods of swing.

6) Initial swing interval: 70%

limits Start of swing
One legged support

Starts with the toes leaving the ground and lasts until the knee reaches a maximum flexion of 65° , the swinging limb lies directly under the trunk next to the contralateral limb.

The hip is in flexion (10°), the knee maximum flexed (65°) and the ankle in plantar flexion (5°).

Objective is forward advancement of the leg without foot drag because there is a narrow space left (0,87 cm) between the toes and the ground.

7) Mid swing

Interval: 85%
limits: Middle of swing

Middle of one leg support

Starts with the maximal knee flexion and lasts until the tibia is in a vertical position in relation to the ground.

The hip is in flexion (20°) and the ankle is in dorsal flexion (5°), in order to further avoid foot drag because the knee

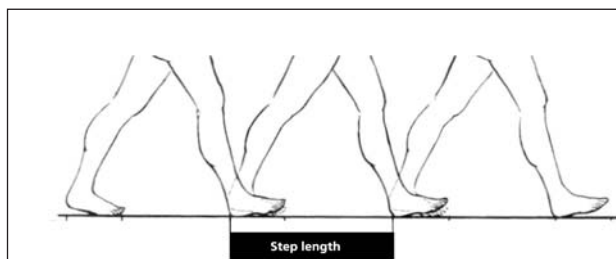


Figure 8. Step length.

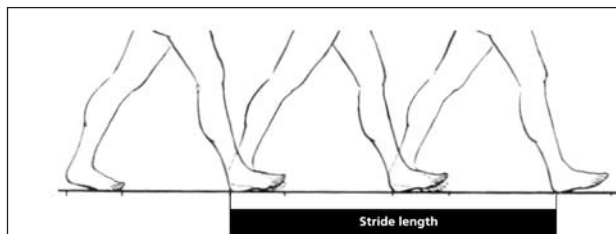


Figure 9. Stride length.

is starting extension (50° flexion).

8) Terminal swing

interval: 100%

limits: Mid of swing

Mid of single support

The tibia swings beyond the vertical position moving ahead of the thigh, the knee is in full extension, the hip in maximal flexion (35°) and the ankle in neutral position (0°).

The advancement of the tibia must be decelerated and the foot prepared for the next landing.

STEP LENGTH

The distance between successive points of heel contact of the opposite feet during double support (Figure 9: distance between right heel contact and left heel contact)¹⁶. In normal gait right step length is equal left step length.

Indicative normal values of step length:

Age	Step length
3 y	0,33m
4 y	0,48m
adults	0,65m

STRIDE LENGTH

The distance between two successive points of heel contact of the same foot.

In normal gait is equal to the double of the step length¹⁶.

Indicative values of stride length

Age	stride length
3 y	0,67m
4 y	0,96m
adults	1,29m

Cadence

The Number of steps per time unit. In normal gait: 100-115 steps/min.

Velocity

The covered distance in a time unit usually measured in m/s. Velocity combines stride length with cadence. It is thought the most reliable indicator for walking ability.

Relation between velocity, stride length and cadence

Velocity is directly proportional to stride and cadence. Acceleration occurs by increasing either the cadence or the stride length.

Normal subjects are increasing both until stride reaches a maximum. Patients try to compensate a short stride by increasing the cadence.

Cadence is indirectly proportional to limb length. Short stature subjects are using a higher cadence¹⁷.

Velocity and cadence are very useful parameters for the clinical assessment.

Relation between velocity and age

Walking starts by the age of 12-15 months. Because of their short limbs toddlers use a higher cadence (170 steps/min in the first year, 140 steps/min in the second year of life). Because stride length almost equals body height a toddler of 0,5m height will have 0,5m stride. Velocity equals height/sec or in other words a child of 0,5m height will have an expected velocity of 0,5m/sec.

The adult walking pattern is reached at the age of 7 years. The different gait parameters are stabilized around the age of 16-18 years¹⁸.

Indicative velocity values according to age

Age	Gait velocity
3 y	0,72m/min
4 y	1,14m/min
adults	1,21m/min

3-DIMENSIONAL CLINICAL GAIT ANALYSIS

INTRODUCTION

Clinical Gait Analysis is a biomechanical measurement which follows a systemic method to capture, display and interpret normal and pathological gait in all three planes (coronal, sagittal, transverse).

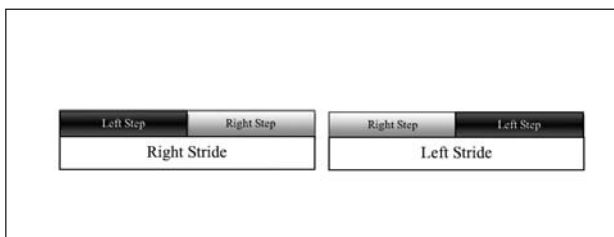


Figure 10. Right and left stride.

Gait disturbances due to movement disorders can be measured and evaluated in comparison to normal gait patterns in order to assess the walking abilities of the patient^{7,19,20,21}.

The procedure includes a combined application of video, computer, force plates, EMG and special software.

Especially designed soft- and hardware are transforming gait video images into a three dimensional motion picture graphic. Trajectories, velocity, moments and angular acceleration are automatically calculated. Ground reaction forces are measured by force plates, muscle function during the gait cycle is recorded by the dynamic EMG and the mechanical work production can be calculated^{22,23,24}.

Clinical Gait Analysis can be performed in a specially designed environment called gait laboratory²⁵. The measurement procedures are standardized and reliably reproducible.

Objective of the Gait Analysis is the creation of a gait report where the primary movement deviation is identified, motion pathology investigated and the locomotor disability is interpreted. Better understanding of gait pathology enhances our capabilities for proper treatment planning while facilitating longterm follow up and enabling validation of locomotor development of the patient²⁶.

GAIT ANALYSIS

Forward motion in a gait cycle can be analyzed in posture alterations of the trunk, the pelvis and the joints of the limbs that occur during the gait cycle in all three planes.

These alterations are equal to the motion trajectories of the different parts of the body. If the normal trajectories are known abnormal deviations can be identified in every interval of the gait cycle.

Capture of these informations is performed in the gait laboratory where motion recording systems (hardware) and special software (programs - algorithms) for processing, measurement and display of telemetry is used.

The recording systems comprise:

a) gait lab walk way with a length of minimum 8 meters where at least two force plates are embedded for 3-dimensional recording of the ground reaction force (GRF) that supports the body

b) Markers placed in selected anatomical points of the

body (trunk, pelvis, femur, tibia, foot)

c) special cameras recording the marker's trajectories

d) EMG

e) P/C etc.

All gained information is processed and displayed in the form of graphs, numerical quantities (angle grades etc), dynamic EMG recording and as a simple video recording.

Gait lab's hard-and software are operated by a trained personnel including:

a) technical department (bioengineer, p/c technician etc): they control the system and operate the laboratory; they are capable to understand the imposed clinical questions and to participate in the interpretation of information gained by the system.

b) clinical department (orthopedist, physical medicine, clinical physiotherapist etc): they have knowledge about the system's function and methodology and expertise to combine the lab's information with the clinical picture and findings of the patient.

The laboratory personnel, in common meetings, collaborate in analyzing all gained laboratory data in correlation with the clinical information (clinical history, examination, range of motion measurement etc); they interpret these findings in a clinically useful way in the form of a report about the patient's disability, the therapeutic planning and suggested interventions.

Gait Analysis comprises kinematics, kinetics, dynamic EMG.

KINEMATICS^{21,22,27,28,29,30,31,32,33}

Describes the motion of objects without consideration of the causes leading to the motion, concentrating in angular displacements and velocities.

Usually the dynamic range of motion (trajectory) of two anatomical segments (i.e. femur-tibia) is measured; that is equal to measuring the angle of a joint (knee) during the different phases of a gait cycle. Measurement unit is grade angle.

In case of Fig.13 the knee angle displacements during the different phases of a gait cycle measured in grades are displayed in the form of a graph.

On the x axis the time intervals of the different phases are expressed as percentage (%) of a gait cycle.

The vertical line in the 65% interval of the gait cycle differentiates the stance phase (on the left) from the swing phase (on the right).

On the y axis the different values of angular displacement are expressed in grades. They are (+) or (-) labeled according to flexion or extension, adduction or abduction etc respectively.

Diagrams (graphs) are addressing frontal, sagittal and transverse planes.

The right leg's graph is colored blue and that of the left is red. Plotting and comparing displacement graphs of any joint of both legs with normal graphs is possible.



Figure 11. Laboratory set up.

KINETICS^{28,34,35,36,37,38,39}

Study of the forces that cause movement. Kinetics reveals the forces causing the above mentioned kinematics.

Forces are divided in:

- Internal originating from the muscles
- External originating from gravity

Internal Forces

It must be reminded that muscle contraction produces force, not motion. Forces are generating moments (angular movement) resulting in displacements (motion).

Muscle force is acting perpendicular to the lever arm, which is equal to the distance from the point of force application to the center of rotation of the joint (where the axis of rotation passes).

A moment is the tendency to rotate, caused by a force acting in a distance from the axis of rotation.

$$\text{Moment} = \text{Force} \times \text{Distance}$$

A moment generates an angular (rotational) velocity around the axis of rotation of a joint.

From kinematics it is known the angular velocity of a joint, i.e. the ankle, during the time intervals of gait. Combining the moment with the angular velocity, the work produced by the muscles acting on the joint can be calculated.

$$\text{Work} = \text{Moment} \times \text{Angular velocity of the joint}$$

It is about the work produced by a muscle group and not by a specific muscle; thus it is proper to refer as the work of a joint and not of a muscle.

The diagram configuration of force, moment and work are similar to the diagrams of kinematics. The x axis refers to the time intervals of different phases as a percentage of gait cycle. On the y axis the different values of force and work expressed in Newton (N) or Nm, W (Watt) are displayed.

For a comparison between different persons to be pos-

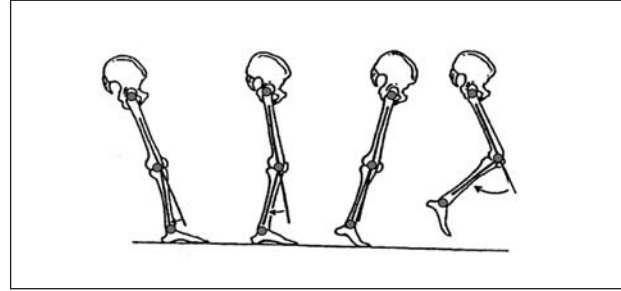


Figure 12. Markers for the knee trajectory.

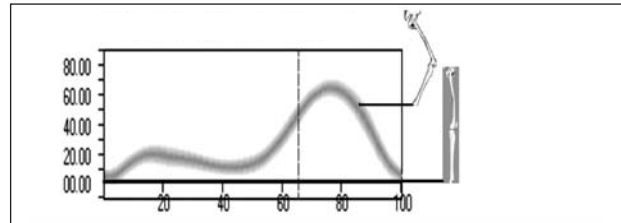


Figure 13. Knee angle graph in a gait cycle.

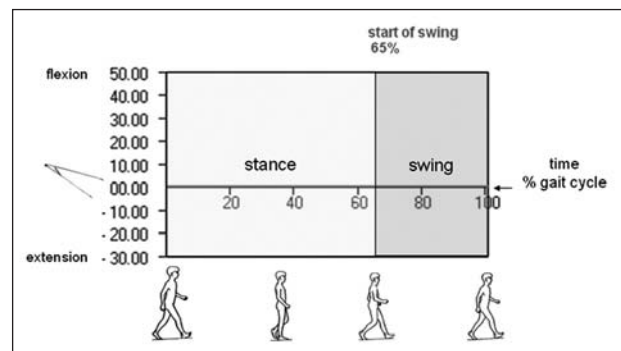


Figure 14. Graph configuration of gait analysis.

sible, force is divided to body weight (BW) and expressed in % BW or Nm/kg, W/Kg.

During interval 0%-15% of gait cycle (1st rocker) ankle joint rotates in plantar flexion ($<10^\circ$), during 15%-45% (2nd rocker) in dorsiflexion (20°) and during 45%-65% (3rd rocker) in plantar flexion.

At the end of loading response (1st rocker) a plantar flexion moment begins that reaches its highest value at the end of stance (50% of gait cycle). During the following preswing this value falls abruptly.

Respectively during 45% of stance (1st and 2nd rocker) negative (-) work is produced (decelarartion).

During the rest 25% of stance positive (+) work is produced (acceleration).

External Forces

The reaction exerted by the floor on the sole of the foot called Ground Reaction Force (GRF) is equal in magnitude

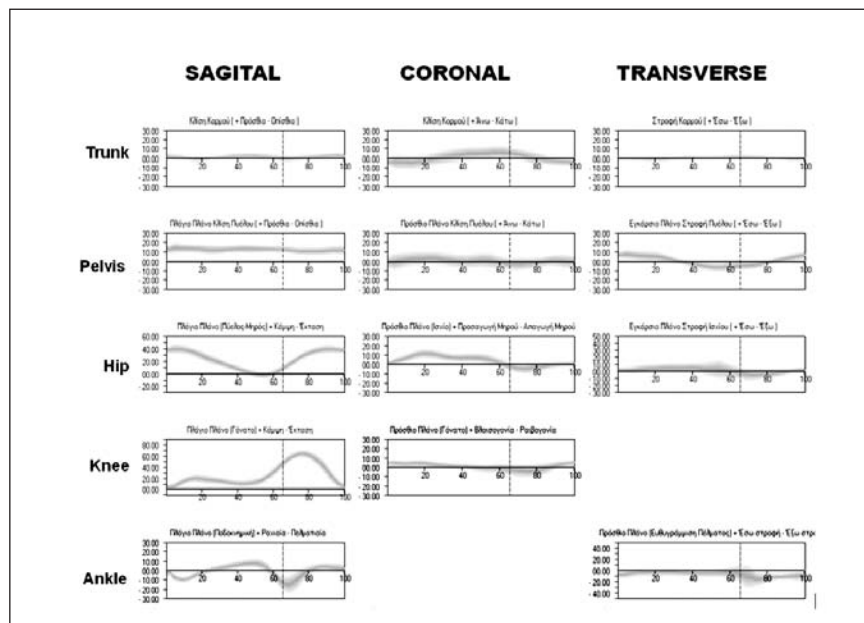


Figure 15. Three planes kinematics diagrams of gait analysis.



Figure 16. Internal moment of the ankle.

and opposite in direction to the force of compression that the body exerts on the floor surface through the sole of the foot (=gravity).

GRF can be resolved in a vertical and a horizontal component. The horizontal can be further resolved in an anteroposterior and a laterolateral component (corresponds to friction). Force plates capture the 3 dimensional vector of the GRF that is displayed according to their orientation as F_z = vertical, F_y = antero-posterior and F_x = latero-lateral force (Figure 18).

- F_z = vertical force
- F_y = antero-posterior force
- F_x = latero-lateral force

GRF acting in a distance from the center of a joint creates a moment that is an angular acceleration around the axis of rotation of the joint.

When internal and external moments around a joint are equal and opposite, forces are in equilibrium, there is no motion in the joint.

In the case that an internal moment produced in a joint (i.e. the ankle joint) by a muscle or a muscle group (i.e. triceps surae) is greater than the moment produced by the GRF (exerted in the metatarsal heads), a motion (plantar flexion) of the ankle joint will appear.

DYNAMIC ELECTROMYOGRAM (EMG)^{14,40,41,42,43,44,45}

Electric signals are produced during muscle function.

Using surface electrodes recording of the main muscle group function is possible.

Muscle function is taking place for a short time interval, in a specific way of order and at a specific time moment of the gait cycle. Abnormal muscle function (either prolonged or out of phase) can be identified.

EMG diagrams of gait share the same configuration like diagrams of kinematic and kinetic analysis. The x axis represents the gait phases expressed in percentage (%) of the gait cycle. The y axis represents values of tension in mv or μv .

There are three categories of muscle function: a) shortening called concentric contraction, b) controlled lengthening called eccentric contraction, c) keeping constant length called isometric contraction.

Function (a) shortening, produces a moment = acceleration around a joint, that is positive work = movement of the joint is produced.

Function (b) lengthening, produces a deceleration moment, that is negative work = energy absorption resulting in motion with decreasing velocity.

In the case of function (c) constant length, there is no moment = work production, there is no movement.

Combining the work values of a joint and the respective EMG values at a specific time interval of the gait cycle, we are capable to know if a muscle's function is shortening or lengthening according to the respectively positive or negative work production.

In the case of work labelled positive (+) = work production, that means the muscle is contracted = shortened, producing acceleration (forward movement).

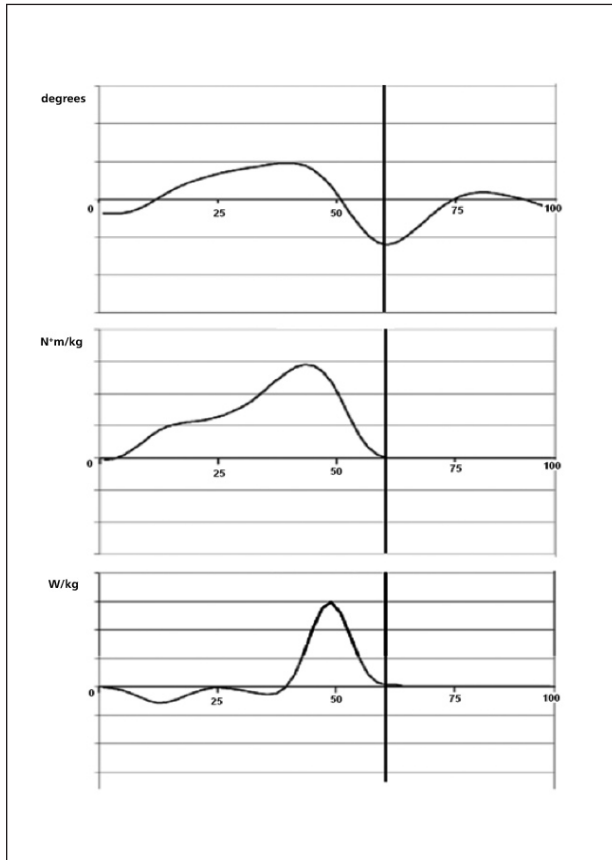


Figure 17. Sagittal plan, ankle joint angle, moment, work.

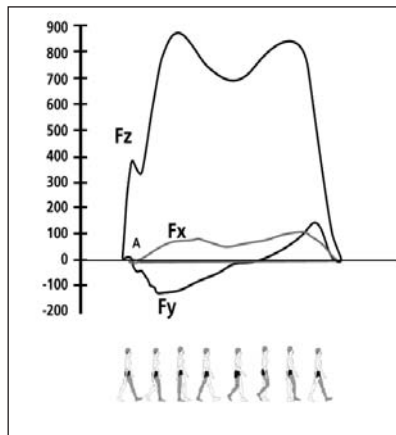
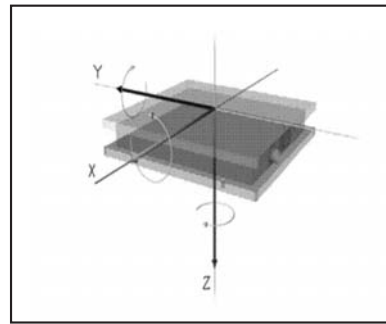


Figure 18. Diagram of vertical (Fz), anteroposterior (Fy), laterolateral (Fx) force.



Figure 19. Internal and external moments of the ankle.



Σχήμα 20. ???

In case of work labelled (-) = negative work = energy absorption, eccentric contraction is occurring causing deceleration

If only moment is produced, that means the joint is motionless (no displacement) because of isometric contraction (constant muscle length)

During 45% of stance (1st and 2nd rocker) negative work is produced (deceleration) while in the rest 20% of stance (3rd rocker) positive work (acceleration) occurs.

Tibialis anterior function during 1st rocker is eccentric contraction (checking the plantarward drop of the foot until touching the ground with the sole) = deceleration.

Function of gastrocnemius during 2nd rocker (15%-40% of stance) is eccentric contraction (checking the forward rotation of the tibia) = deceleration.

Function of gastrocnemius during 3rd rocker is concentric contraction (plantarflexion of the foot at the ankle to produce propulsion at the end of stance) = acceleration.

At the end of a kinetic gait analysis the movement of the joints, in the form of diagrams and that of numerical values is known. Normal and abnormal moment production can be calculated, the functional status of the muscles and their participation in the work production of the joints estimated. We are capable to assess if the movement is normal, the possible deviations and the time interval of the gait cycle they occur.

GAIT ANALYSIS REPORT^{5,6,46,47}

All mentioned data are evaluated in combination with the clinical history and examination of the patient.

The 3-Dimensional Clinical Gait Analysis Report incorporates the study, and evaluation of all the recorded laboratory and clinical parameters. The conclusions relative to the gait pathology comprise investigation of the causing mechanisms and treatment suggestions to enhance the rehabilitation strategies of the gait function.

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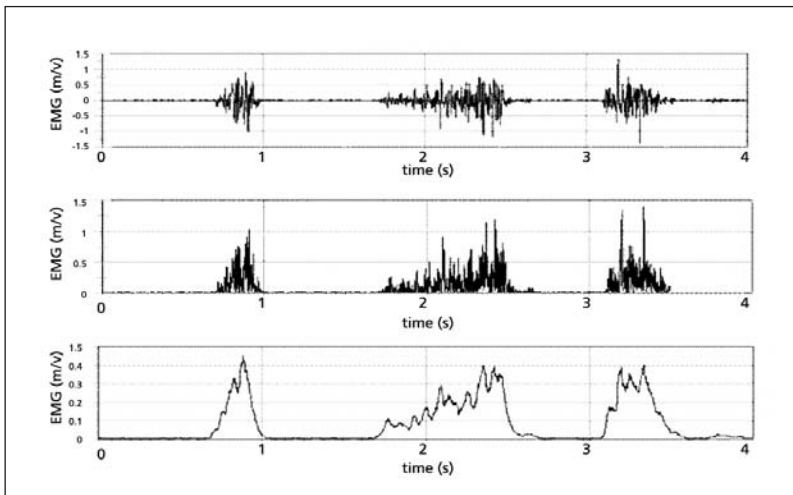


Figure 21. Row, rectified and filtered EMG signal.

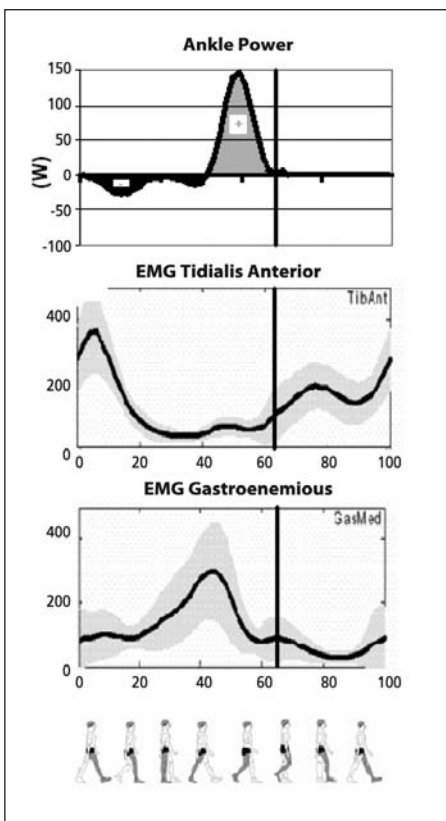


Figure 22. Combined kinetic and EMG findings.

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