Motion Times
Journal for the motion-capture community
Issue 2-06

Lower Extremity Amputation

Gait analysis

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Human gait is a complex task, it's fundamental objective is to move safely and efficiently from one point to another. This is accomplished using cyclical and highly automated movement pattern, with rhythmical, alternating motions of the trunk and extremities. Gait analys is involves the reduction of this continuous process in to a number of defined parameters for quantification, evaluation and comparison.

Gait analysis at different levels can be useful in the evaluation and optimisation of the gait of individuals with lower extremity amputation. In our institution we find it particularly helpful in monitoring there habilitation progress, the effectiveness of a particular intervention or component selection and in providing detail information useful in the quantification and results of prosthetic alignment adjustments with the goal of gait optimisation.

Normal Locomotion

It is important, from a clinical stand point, to understand the events of the walking cycle. Pathological locomotion can then be correlated to the normal cycle in order to ascertain cause and effect of any abnormality.

Functional locomotion is concerned with simultaneously solving five basic motor problems: (1) the generation of mechanical energy for controlled forward progression, (2) absorption of mechanical energy to minimise shock and/or to decrease the forward upright position, (4) support of the upper body on the lower limb during the stance phase, and (5) control of the lower extremity trajectory to assure appropriate articulation with the ground during the stance phase and clearance of the foot during the swing phase.

Under normal conditions, comfortable walking speed corresponds to the speed at which the energy cost per unit distance is minimum. Energy efficiency is dependent on unrestricted joint mobility and the precise timing and intensity of muscle action. The result of abnormal gait biomechanics is increased energy cost, usually with a compensatory decrease in walking speed. Thus, patients with lower limb amputations, that have a normal cardio-pulmonary mechanism and nutritional status do not ordinarily expend more energy per minute than able-bodied persons, although the energy required per unit distance is increased.

Gait Analysis

Clinicians routinely do informal, visual analysis of gait in the patients with leg amputation. This type of analysis does not provide quantitative information and has many limitations due to the speed and complexity of human locomotion. This is further complicated by the gait deviations and compensations present in the walking pattern of individuals with lower extremity amputation. Gait can be studied through the collection of a wide range of information in the laboratory using optoelectronic technology and force platforms. In our laboratory we perform such an evaluation using two CX1 CODA units and 4 specially designed force platforms. A major advantage provided by these system is the speed of data acquisition and processing which is essential to allow for efficient use of clinician's and patient's time for effective assessment and intervention on the gait of the subject under evaluation. Something that most other gait analys is systems have difficulty achieving.

Kinematics

Temporal and Spatial Descriptive Measures

Temporal-spatial foot fall patterns are the end product of the total integrated loco motor movement. In order to characterise gait, basic variables concerning the temporo-spatial sequencing of stance and swing phases are measured. A CODA report print out provides calculated data about walking velocity, cadence,

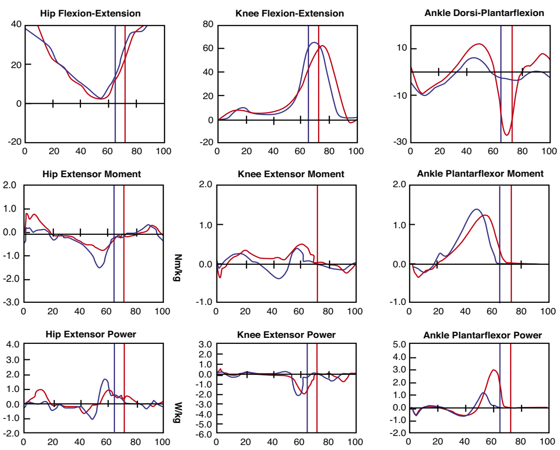
no assist

Gait Analysis Report MossRehab Hospital

Patient Data:	Gender	Age	Date of Birth	Height (m)	Weight (kg)
	Male	19	12/80	1.809	71

Gait Parameters	Left	Right	Normal
Speed (m/s)	1.04	1.04	1.07
Stride Length (m)	1.38	1.40	1.34
Stride Time (s)	1.32	1.34	1.25
Strides/Minute	45.28	44.78	47.81
Step Length (m)	0.69	0.71	0.67
Step Time (s)	0.67	0.67	0.63
Steps/Minute	89.29	89.55	95.62
Percent Stance	64.98	72.31	71.16
Single Support (s)	0.37	0.46	0.36
Double Support (s)	0.21	0.30	0.27

Joint Angles (deg)	Left	Right	Normal
Hip Range	39.00	41.30	34.60
Hip Max	41.90	43.60	30.50
Hip Min	2.90	2.30	-4.10
Knee Range	64.30	63.70	52.60
Knee Max	64.10	61.60	53.90
Knee Min	-0.20	-2.10	1.30
Ankle Range	16.10	38.40	22.00
Ankle Max	6.10	11.70	9.80
Ankle Min	-10.00	-26.70	-12.20



stance and swing times for each foot as well as stride lengths and step lengths. By comparing the two sides, measures of symmetry can be obtained to determine the extent of unilateral impairment and the impact of interventions on symmetry of walking.

Motion Analysis

CODA kinematic data provides a description of movement without regard to the force generating it. The kinematic information is available instantaneously as co-ordinate data. It can be processed and displayed as a function of time or as a percent of the gait cycle. Derived data including joint angles, angular velocities, acceleration and limb segment rotation are of great utility in the evaluation process.

In our laboratory we also use four large platforms placed adjacent to each other for data collection so that the forces transmitted through the contact surface for each foot can be recorded simultaneously and independently to generate the kinetic data.

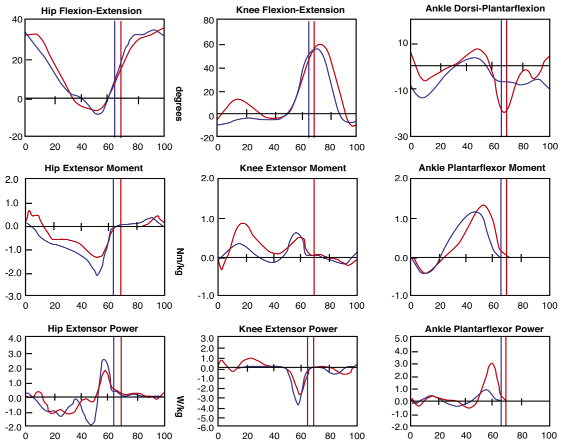
For comparison velocity matched normative data with +/- two SD are plotted. The magnitude of the ground reaction forces and its relationship to joint centers are the factors that determine moments, or torque about a joint, which will indicate the direction and magnitude of rotation.

L prosthesis, no assist

Gait Analysis Report MossRehab Hospital

Patient Data:	Gender	Age	Date of Birth	Height (m)	Weight (kg)
	Male	21	12/80	1.809	75

Gait Parameters	Left	Right	Normal	Joint Angles (deg)	Left	Right	Normal
Speed (m/s)	1.21	1.20	1.07	Hip Range	43.10	41.60	34.60
Stride Length (m)	1.51	1.46	1.34	Hip Max	34.70	35.50	30.50
Stride Time (s)	1.25	1.22	1.25	Hip Min	-8.40	-6.10	-4.10
Strides/Minute	48.00	49.18	47.81				
Step Length (m)	0.82	0.69	0.67	Knee Range	65.40	69.50	52.60
Step Time (s)	0.67	0.58	0.63	Knee Max	55.60	58.70	53.90
Steps/Minute	89.42	103.81	95.62	Knee Min	-9.80	-10.80	1.30
Percent Stance	64.64	68.85	71.16	Ankle Range	16.60	27.10	22.00
Single Support (s)	0.38	0.44	0.36	Ankle Max	3.40	7.60	9.80
Double Support (s)	0.23	0.20	0.27	Ankle Min	-13.20	-19.50	-12.20



Clinical Gait Analysis in Amputees

Pathologic gait results from lower limb amputation. Gait analysis can be used to evaluate the dynamic basis for an observed gait deviation. It is also a valuable aid to objectively assess the impact of various treatment interventions, prosthetic components, dynamic alignment and to develop objectives election criteria for different prosthetic options. Examples of such interventions may include: 1) the application of different prosthetic change in the height of the prosthesis.

Following are examples of component selection differences and height adjustments with resulting gait improvements as documented by 3D gait analysis. Data collected at Moss Rehab from a transfemoral amputee using a 7 bar multi-ax is knee (Century) and a micro processor controlled C-leg (Otto-Bock).

Gait analysis combined with sound clinical judgment plays an important role in elucidating the factors involved in pathological prosthetic gait and the selection and effects of available interventions to optimise it.

Additional Reading

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Advancing our understanding of walking on a treadmill: Implications in Neurorehabilitation

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In the Galileo's book, Dialogue concerning the two chief world systems, Salivati explains a ship experiment to Simplicio and Sagrado. A person throws a stone straight-downward from a mast inside a motionless ship and a ship moving a constant speed. The stone in the two different situations is dropped at the same position of the deck and takes the same time period from the mast to the deck despite one ship moving and the other stationary. This story makes us think about relativity of motion of a subject inside motionless and moving environments. When we walk inside an airplane, it is easy to forget that the airplane flies at the very high yet constant speed. Inside the flying airplane, we would walk the same way as we do on the still airplane parked at the airport. In other words, we would experience similar physical events like the stone does in the Salivati's story. What does this concept have to do with locomotion? What happens when a person walks on a treadmill? Is it the same experience as walking over-ground, in the community?

This question is not just for proving our scientific curiosity of the relativity of motion; it has profound ramifications to the field of neurorehabilitation. That's because treadmill training has become a major staple in rehabilitation programs that focus on restoring walking ability in individuals with neurological disorders. There are tremendous advantages to training individuals with gait impairments on a treadmill. For example, subjects can execute many steps in a small contained space, and since their legs remain in a small area, therapists can assist the movement without having to crawl along the ground. Furthermore, over-head unloading systems can be used to provide partial body-weight support to those who may be weight support to those who may be experiencing weakness in their lower extremities. Because of these advantages, body-weight supported treadmill training has become popular throughout rehabilitation centers world wide.

Since the goal of all patients is to walk at home and in the community, there is a fundamental question that needs to be raised: "Is walking on a treadmill the same as walking over-ground?" Based on Salivati's theory, one might think yes. But in reality, two fundamental assumptions need to be made. First, the speed of the treadmill must remain constant, otherwise walking on a treadmill becomes similar to walking on an airplane accelerating down a runway. And second, the motor control strategy utilised during over-ground walking is the same as the one utilised on a treadmill. To date, various research studies have shown some key differences between the two walking modalities by

Figure 1.
Codamotion markers are placed on subject's legs and pelvis to track motion during treadmill and over-ground walking trials.

looking at joint angles [3], muscle activity [4], and temporal gait parameters (e.g. step length, stride time, and cadence) [5,6,7]. However, none of these studies have looked at joint moments and joint powers utilised during treadmill ambulation, primarily because of the limitations in the ability to accurately resolve ground reaction forces and centers of pressure while subjects walk on the treadmill.

At that National Rehabilitation Hospital in Washington DC USA, The Center for Applied Biomechanics and Rehabilitation Research (CABRR) is tackling this issue where for the first time, they are able to perform full 3-dimensional inverse-dynamics during treadmill walking. Dr. Joe Hidler, Associate Professor in the Department of Biomedical Engineering at Catholic University and the Director of CABRR, along with Song Joo Lee, a graduate student at Catholic University,

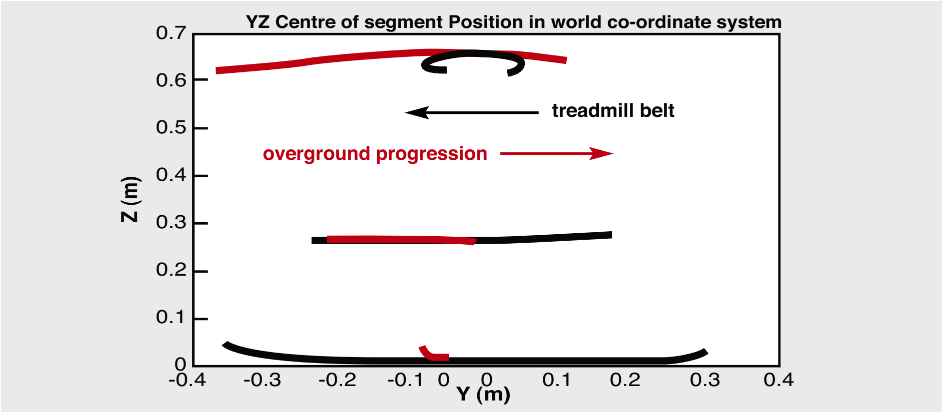

Figure 3.
Movement of the foot, shank, thigh segments during both treadmill and over-ground gait.

are conducting a study that is comparing joint kinematics, muscle activation patterns and joint moments and powers in healthy subjects walking on both the treadmill and over-ground. Utilizing a Codamotion tracking system (CX1048, Charnwood Dynamics, UK) placed approximately 10 feet in front of the treadmill, 28 markers are placed on the subjects legs and pelvis to track limb movement (Figure 1). An ADAL-3D-COP split-belt instrumented treadmill (Tecmachine, Andrezieux Boutheon France) that contains Kistler tri-axial force sensors (Winterthur Switzerland) is used to resolve ground reaction forces and centers of pressure under each foot. For over-ground gait, the treadmill is turned off and acts as two large force plates as the floor of the lab is level with the treadmill surface.

In the study, marker data collected from the Codamotion is merged with the ground reaction force data and imported into Visual 3D gait software (C-Motion, Rockville MD, USA). In Visual 3D, joint angles, moments and powers are computed for both over-ground and treadmill trials using patient specific models. An example Visual 3D model for a subject during over-ground gait is shown in Figure 2.

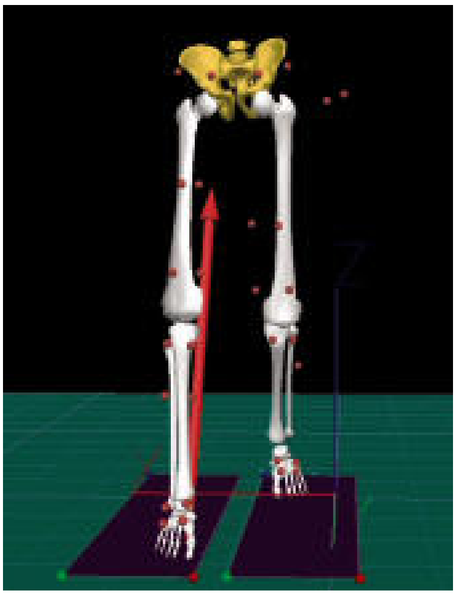

Figure 2.
Visual 3D model where the small red balls represent Codamotion markers and the red arrow under the left foot is the ground reaction force.

While this study is not yet complete, there appear to be differences between the two walking modalities in a number of gait metrics. It appears that these differences can best be explained by the differences in the task, illustrated in Figure 3. Shown in black are traces of the movement of foot, shank and thigh segment centers during treadmill walking. For treadmill trials, the hip remains fairly stationary while the foot and shank start anteriorly and progress in the direction of the treadmill. Conversely, during over-ground gait, subjects plant the foot, and the leg and subsequently the subject's center of mass vaults over the foot. So in the case of the treadmill, the foot moves with respect to the hip while during over-ground gait, the hip moves with respect to the foot.

Mathematically, if the speed of the treadmill is constant, similar joint moments should result. Yet in reality, whether it is the pacing of the treadmill or the differences in motor strategy, muscle activation patterns, joint moments, and kinematics appear to adjust to each respective condition.

To learn more about this and other CABRR projects, visit http://cabrr.cua.edu.

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Two Prestigious Awards for Prof Tim O'Brien

Our photograph shows Prof Tim O'Brien and family as the Irish Minister of Health presents his Lifetime Achievement Award from the Irish Journal of Medical Science/Royal Academy of Medicine in Ireland.

Prof. O'Brien was also presented with the John Sharrard Memorial medal and Honorary Membership of the British Society for Children's Orthopaedic Surgery at a ceremony in the Central Remedial Clinic on May 10th, 2006. He was one of three recipients of this prestigious award. The award was presented by Mr. David Hunt and Mr. James Robb, President and Secretary of the Society. Mr. Hunt acknowledged the contribution made by Prof. O'Brien to the study of hip dysplasia, especially the classification of damage to the femoral epiphysis following treatment and how this could be prevented and treated, and also his pioneering work on gait analysis in cerebral palsy.

Prof. Tim O'Brien established the Clinical Gait Laboratory in 1989 with Ann Jenkinson (Senior Physiotherapist) at the CRC. In addition to gait analyses and research, the mobile gait lab service has been developed by Mr. Mike Walsh (Manager of the Gait Laboratory) and his team to provide an outreach specialist service.

HSE Innovation Award for CRC mobile gait lab

The gait laboratory team were presented with a Special Merit Award by An Tánaiste and Minister for Health and Children, Mary Harney at the HSE Innovation Awards ceremony in Dublin Castle. This award for *"Innovations in Management and Administration of Services/Support, including Innovative Use of Technology/Communications"* was presented for the ***mobile gait laboratory service*** *(see worlds first mobile gait laboratory; issue 03 04 and 01 05 www.motiontimes.com).* The National Health Innovation Awards are designed to reward innovation in the health services, and are sponsored by the Health Service National Partnership Forum. Over 250 entries were received from organisations and teams throughout the country including most of the large teaching hospitals. ***The mobile gait lab has attracted interest from all over the world and this innovation has now been recognised by the HSE by this Special Merit Award.***

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