Physical Modeling of Normal and Pathological Gait Using Identification Of Kinematic Parameters

C. A. Collazos and R. E. Argothy

***Abstract*—**This paper present the one-dimensional gait kinematic principle, in order to identify the kinematic parameters for Normal and Pathological (transtibial amputation) Gait of two subjects with similar anthropometry. Each type of gait is associated with uniform linear motion and uniformly accelerated motion. We use Manuela Beltrán University Biomechanics Laboratory.The physical modeling developed complements the information of the data acquisition system and is used for the biomechanics modeling.

***Keywords*—**Gait, kinematic, modeling, physics, prosthesis

I. INTRODUCTION

THE gait analysis is the measurement and assessment of human locomotion which includes both walking and running [1]. These movements, known as stereotyped reflexes, are characterized by being repetitive in time when the velocity and the acceleration are constant [2]. Therefore, it is possible to obtain reference curves at each movement phase that could help to determine abnormalities or pathologies which are related to the musculoskeletal system and modify normal behavior [3].

The different tissues involved during walking namely: muscles, tendons, cartilage, ligaments, connective tissue (fascia) and the bone component, perform different functions such as motion generation, power transmission, buffer loading, joint stabilization of segments, among others. These functions are the basis of motion and therefore are constantly analyzed and evaluated to determine alterations that modify their performance [4], [5].

Subjects with lower limb amputations, have compensatory adjustments in gait where the soft tissues and the mechanical stress of the body must adjust to the structural and functional changes in this one. This suggests an increased muscular demand, energy expenditure, the alignment of gravity center and mass center, the static and dynamic postural alignment among others. These parameters are relevant for measuring the risk factors presented by these subjects, such as falling due to alterations in the stability and balance control of the body [6] [7],[8].

The aim of this work is to compare the gait analysis to healthy and pathological subjects. In this research, pathological gait refers to prosthetic gait transtibial amputation. The motion analysis techniques used to measure accurately kinematic curves are obtained through skin markers, which record the position, velocity and acceleration of a body segment. These measurements provide quantitative information about the movement [9].

A complete review of human walking modeling and simulation is presented in [10], [11], [12], [13]. This research review focuses on physics-based human walking simulations in biomechanics literature and the robotics. The gait synthesis methods are broadly divided into five types: inverted pendulum model; passive dynamics walking; zero moment point methods; optimization-based methods; and control-based methods [11],

This paper describes the behavior of the Normal and pathological gait at a constant velocity and acceleration. We identify the kinematic parameters for each type of gait and compare the kinematics curves presented in each of the cases.

The article is structured as follows: Section II shows the instrumentation used and the associated markers for gait evaluation. Section IV presents the identification of the kinematic parameters related to the gait and the mathematical tools. Finally Section V is dedicated to the discussions and conclusions.

II. INSTRUMENTATION

Manuela Beltrán University Biomechanics Laboratory was used for data logging. We use BTS GAITLAB [14]. This acquisition system of high precision for motion analysis has six optoelectronic cameras that measures the displacement ($\pm 10^{-7} m$) of body segments in time ($\pm 10^{-2} s$).

The device has 3 markers placed strategically as Fig. 1 indicates. The markers involved in the gait were the sacrum (marker 6), the right greater trochanter (marker 7) and the left greater trochanter (marker 8). The study of movement in this work is restricted to the X axis only.

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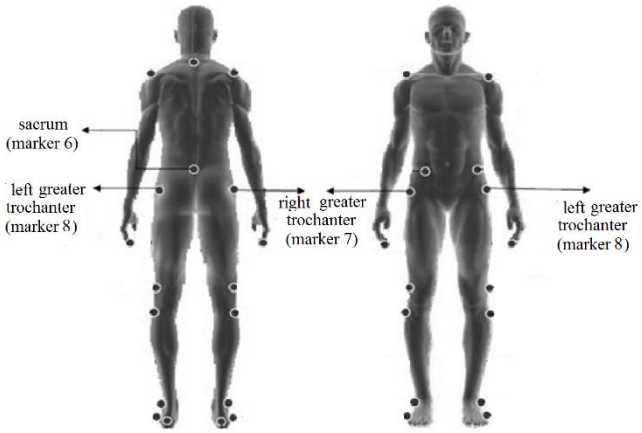

Fig. 1. Disposition of the cutaneous markers in the human body [14]

III. METHOD, RESULTS AND ANALYSIS

We use the physical fundamentals of the one-dimensional kinematic. For the data analysis the least squares and correlation coefficient methods were used [15]. The test was applied for two subjects of (34 ± 1) years old male, height (1.64 ± 0.01) m and mass of (64 ± 0.1) kg. The first subject has unilateral transtibial amputation of right lower extremity. The second subject has a normal gait and an anthropometry like that of the first subject. The study was approved by the Ethics Committees of the Manuela Beltrán University. Written informed consent was obtained by the patients.

The figures 2 to 6 show experimental data in dotted line and models in continuous black line. We use squares for Normal Gait and points for Pathological Gait. The units for all variables and parameters are represented in the International Units System.

A. Normal and Pathological Gait with constant velocity

Fig. 2 illustrates the trajectories for Normal and Pathological Gait. This figure indicates the position register towards the sacrum (marker 6) and the linear interpolation of the two trajectories. Here, it is observed that there is a high correlation between the model and the experimental data for Normal Gait. This correlation is significantly statistical ($r = 0.997$). The identification of the model allows determining the initial position (x_0 =-2.13m) and the average velocity on the walk (v_0 =1.00m/s). The model of the position in function of time for Normal Gait is therefore $x(t) = -2.13 + 1.00t$. We observed that there is a high correlation between the model and the experimental data for Pathological Gait. This correlation is significantly statistical ($r = 0.997$). The identification of the model allows determining the initial position (x_0 =-2.12m) and the average velocity on the walk (v_0 =0.60m/s). The model of the position in function of time for Pathological Gait is therefore $x(t) = -2.12 + 0.60t$. We use the relative error defined as: $\%E = \left[\frac{control - experimental}{control}\right].100\%$, to compare Normal Gait (control value) and Pathological Gait (experimental value) average velocity. In this case we obtain a relative error of $\%E$=39.60%.

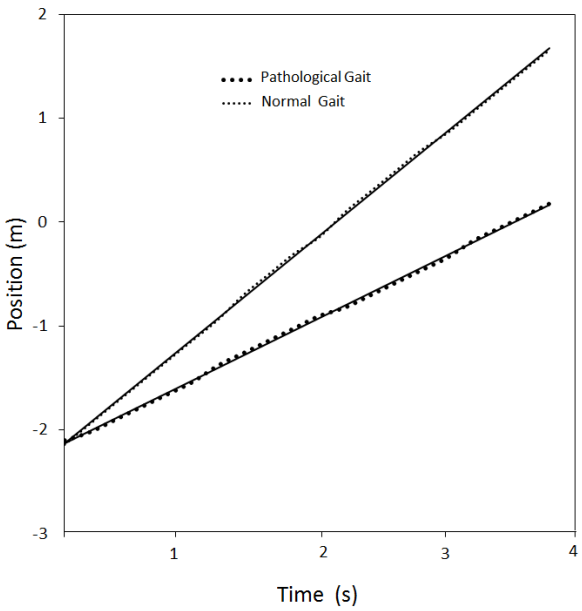

Fig. 2 The position–time graph on the X axis for the sacrum with constant velocity.

Fig. 3 shows the position registered towards the right greater trochanter (marker 7) and the linear interpolation for Normal and Pathological Gait. The identification of the model for Normal Gait determines the initial position (x_0 =-213m) and the average velocity in the normal gait (v_0 = 1.02 m/s). Here can be seen that there is a high correlation between the position and the experimental measurements with $r = 0.996$. The model of the position in function of time for Normal Gait is therefore $x(t) = -2.13 + 1.02t$. The identification of the model for Pathological Gait determines the initial position (x_0 =-2.12m) and the average velocity in the pathological gait (v_0 = 0.61 m/s). Here can be seen that there is a high correlation between the position and the experimental measurements with $r = 0.996$. The model of the position in function of time for Pathological Gait is therefore $x(t) = -2.12 + 0.61t$. In this case we obtain a relative error of $\%E$=39.60% for average velocity.

Fig. 4 indicates the position register to the left greater trochanter (marker 8) and the linear interpolation for Normal and Pathological Gait. The identification of the model for Normal Gait determines the initial position (x_0 =-2.13m) and the average velocity on the gait (v_0 =0.99 m/s). In this case the correlation coefficient is $r = 0.996$.The model of the position

in function of time for Normal gait is consequently $x(t) = -2.13 + 0.99t$. The identification of the model for Pathological Gait determines the initial position (x_0 =-2.12m) and the average velocity on the gait (v_0 =0.59 m/s). In this case the correlation coefficient is $r = 0.996$. The model of the position in function of time for Pathological Gait is consequently $x(t) = -2.12 + 0.59t$. In this case we obtain a relative error of $\%E$=40.00% for average velocity.

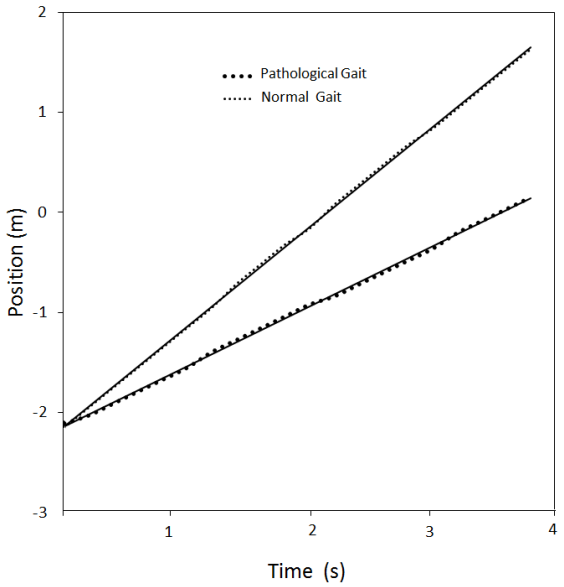

Fig. 3 The position–time graph on the X axis to the right greater trochanter with constant velocity

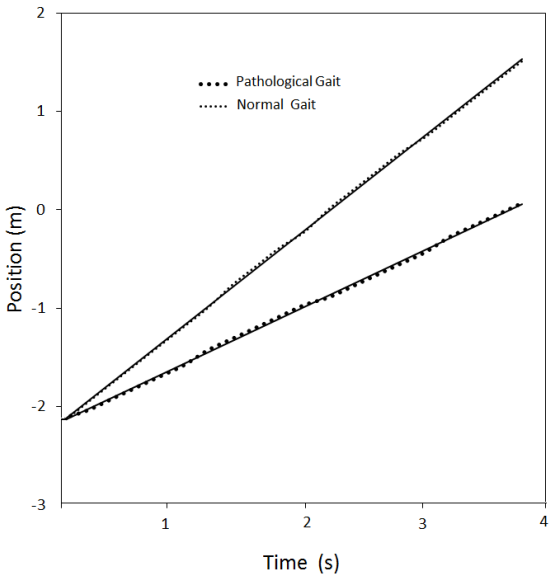

Fig. 4 The position–time graph on the X axis to the left greater trochanter with constant velocity

Based on physical models found for the sacrum, for the right and left greater trochanter, notice that our experimental data support the model reasonably well. We observed a 0.99 higher correlation between the kinematic models for position and the measurements, which meets the characteristics of a uniform linear motion according to [15]. We found significant differences between the average velocity of the normal and pathological gait in the three markers. The velocity relative error $\%E$ is around of 39% for the sacrum, for the right and left greater trochanter

B. Normal and Pathological Gait with constant acceleration

Fig. 5 illustrates the trajectories for Normal and Pathological Gait. The Figure 5 indicates the position registered towards the sacrum (marker 6) and quadratic interpolation of the two trajectories. The identification of the model allows determining the initial position (x_0 =-2.13 m), initial velocity (v_0 =-1.09 m/s) and half of the average acceleration (0.90 m/s^2) for Normal Gait. There is a high correlation between the model and the experimental data ($r = 0.997$). The model of the position in function of time for Normal Gait consequently is $x(t) = -2.13 - 1.09t + 0.90t^2$. The identification of the model for Pathological Gait determines the initial position (x_0 =-2.27 m), initial velocity (v_0 =-0.31m/s) and half of the average acceleration (0.29 m/s^2). There is a high correlation between the model and the experimental data ($r = 0.997$). The model of the position in function of time for Pathological Gait consequently is $x(t) = -2.27 - 0.31t + 0.29t^2$. In this case we obtain a relative error for average acceleration of $\%E$=71% and of $\%E$=67% in initial velocity.

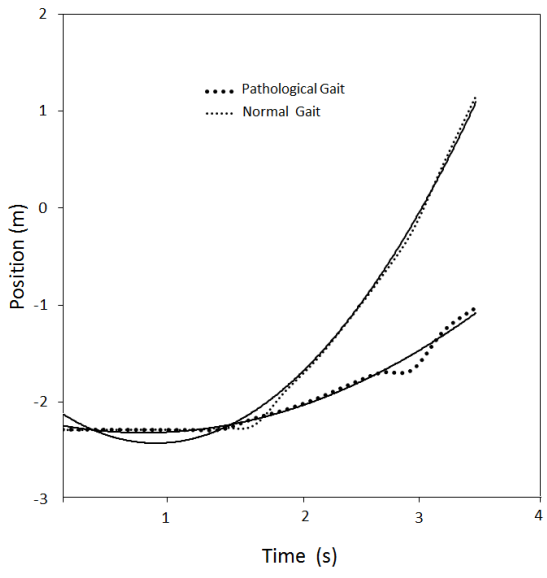

Fig. 5 The position-time graph on the X axis to the sacrum with constant acceleration

Fig. 6 indicates the position registered towards the right greater trochanter (marker 7) and the quadratic interpolation. for Normal and Pathological Gait. The identification of the

model for Normal Gait allows determining the initial position (x_0 =-2.10m), initial velocity (v_0 =1.18 m/s) and half of the average acceleration (0.91 m/s^2). Like we can see there is a high correlation between the position and the experimental measurements ($r = 0.996$). Hence, the model of the position in function of time for Normal Gait is $x(t) = -2.10 - 1.18t + 0.91t^2$ .The identification of the model for Pathological Gait determines the initial position (x_0 =-2.27 m), initial velocity (v_0 =-0.33 m/s) and half of the average acceleration (0.31 m/s^2). There is a high correlation between the model and the experimental data ($r = 0.997$). The model of the position in function of time for Pathological Gait consequently is $x(t) = -2.27 - 0.33t + 0.31t^2$. We obtain a relative error for average acceleration of $\%E$=72% and of $\%E$=65% for initial velocity.

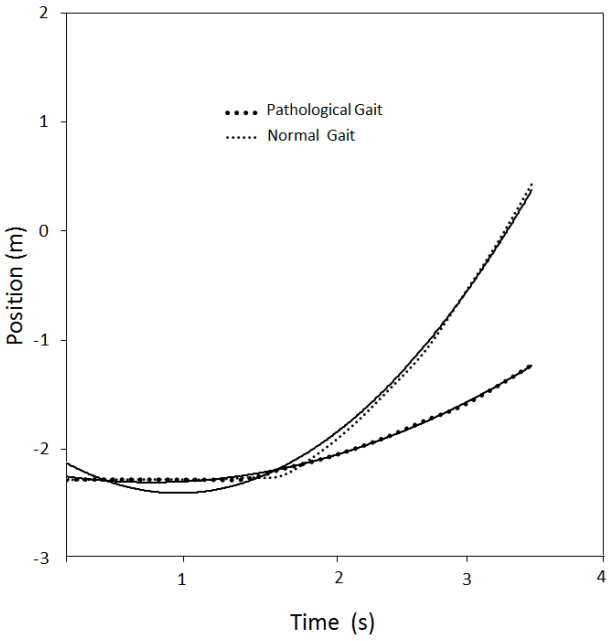

Fig. 6 The position-time graph on the X axis to the right greater trochanter with constant acceleration

Fig. 7 indicates the position register to the left greater trochanter (marker 8) and the quadratic interpolation for Normal and Pathological Gait. The identification of the model for Normal Gait allows determining the initial position (x_0 =-2.15m), initial velocity (v_0 =1.06 m/s) and half of the average acceleration (0.89 m/s^2) for Normal Gait. Here can be seen that there is a high correlation between the model and the experimental data ($r = 0.997$).The model of the position in function of time for Normal Gait is $x(t) = -2.15 - 1.06t + 0.89t^2$.

The identification of the model for Pathological Gait determines the initial position (x_0 =-2.27 m), initial velocity (v_0 =-0.30 m/s) and half of the average acceleration (0.29 m/s^2). There is a high correlation between the model and the experimental data ($r = 0.997$). The model of the position in function of time for Pathological Gait consequently is $x(t) = -2.27 - 0.30t + 0.29t^2$. In case we obtain a relative error for average acceleration of $\%E$=70% and of $\%E$=67% for initial velocity.

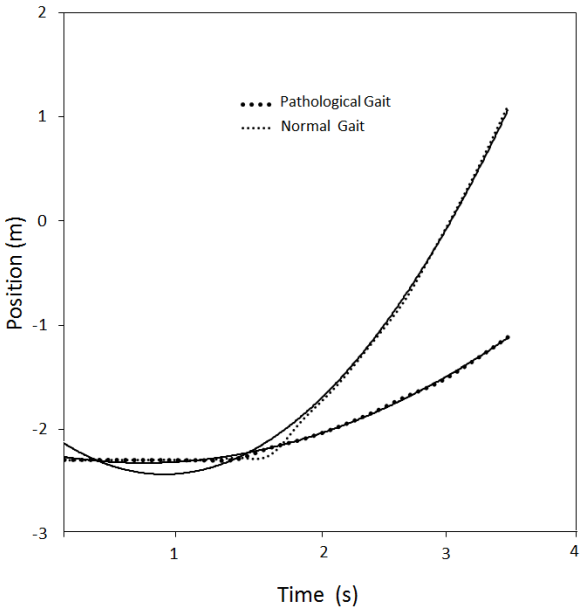

Fig. 7 The position-time graph on the X axis to the left greater trochanter with constant acceleration

According to kinematics curves and mathematical models found for the sacrum, for the right and left greater trochanter, we observed a 0.99 higher correlation between the kinematic models for position and the experimental measurements, which meets the characteristics of a movement with constant acceleration regard to [15]. We found significant differences between the parameters of Normal and Pathological Gait in the three markers. The relative error $\%E$ for initial velocity is around of 69% for the sacrum, for the right and left greater trochanter. The relative error $\%E$ for average acceleration is around of 70% for the three markers.

V. CONCLUSION

This work has presented a simple model to Normal and Pathological Gait. Experimental results were theoretically validated for the physical models and parameters found. The technique used involves three reference markers (sacrum, right and left greater trochanter,) related to the center of mass of the human body. The identified models predict in time quantities such as position, velocity and acceleration at the different types of motion with constant velocity and acceleration. Orders of magnitude found for the physical models of position are within the range of magnitudes reported by authors like Winter in [9].

This work compare physical models between Normal and Pathological Gait. It is known that the normal gait may be affected in subjects with unilateral transtibial lower limb aputacion where the musculoskeletal system and soft tissues that help maintain the dynamic mechanism of the body are compromised. It is for this reason that the compesatory in pelvic floor and lower limbs are notorious in gait of people with amputation as you can see in the graphics of trajectory

In this sense our purpose in future is to establish a three-dimensional kinematic modeling involvement other markers such as hip, knee and ankle depending on the level of amputation for determining characteristic patterns in each study subject.

It is important to note that the normal gait pattern modeling can be affected by many causes, such as size, age, footwear, terrain, load, activity of the subject, which are not necessarily pathological but are related to the alteration or adaptation of musculoskeletal structures for movement. In this case we can generate in future works to do comparisons of the gait in different pathologies.

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