STUDY OF BIOMECHANICAL CURVES IN A MOTION ANALYSIS LABORATORY AND A THERAPEUTIC ROBOTIC SYSTEM

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Abstract: The Motion Analysis Laboratory (MAL), generates a set of biomechanical curves (kinematic and kinetic), from patient records during gait cycles, based on time in all three planes. The Lokomat robotic system (LRS) generates the same curves (but is however, restricted to only the sagittal plane, by way of bilateral hip and knee sensors) when acting with patients who are undergoing training or simulating the gait cycles, at an average speed of 2.35 km/h. The aim of this paper is to evaluate LRS gait cycles by a quantitative comparison with the gait of normal subjects. For this purpose, the correlation coefficient (CC) and the significance probability function (Zsc) were calculated. The results show a greater similarity between kinematics parameters. However, with the kinetic curves, the relationship is not so obvious. The obtained scatter diagram was analyzed while simultaneously plotting the hip and knee curves taken from the LRS, when acting with patients who have undergone varying powers of the LRS servomechanisms from 100% to 50% and 30%.
Keywords: Motion Analysis Laboratory, Lokomat robotic system, lower extremity joint biomechanical curves.

Introduction

The Motion Analysis Laboratory (MAL) of BTS is a diagnostic system and generates a series of tridimensional curves of different biomechanical parameters, kinematic and kinetic, collected from patients presenting various neuromuscular skeletal pathologies from the bilateral joints of the pelvis, hip, knee and ankle. These curves are compared to a set of reference norms (SRN) made up of average values of each parameter and their respective standard deviations.

Lokomat robotic system (LRS) is a therapeutic system that generates angular curves of kinematic and kinetic parameters from bilateral hip and knee sensors of the system on the sagittal plane.

The idea of comparing the two systems stems from the concern of distinguishing if the robotic system behaves the same way a normal human subject does during walking.

The aim of this paper is to compare the curves yielded by the LRS to those by MAL in order to establish possible relationships between the two systems.

This relationship will allow us to evaluate the operation of LRS in patients undergoing therapy, at different levels which the joint servomechanisms (JSM) undergoes, and thus identify potential changes generated by the actions of patients.

Methods

Elite Clinic's MAL system generates nine angular curve kinematic parameters in function of time and space. Each curve has been normalized relative to a gait cycle, equivalent to a column of 100 values. Therefore, the matrix of data from a patient is of 18 x 100 values.

The SRN is established by a matrix of data from normal subject and is equivalent to the same nine angular curves for each extremity, with values representing the averages of 40 normal subjects with their respective standard deviations.

Figure 1 shows the angular curves of 9 joints: pelvis, hip, knee and ankle, which constitute the SRN (black lines) and from a patient (blue lines).

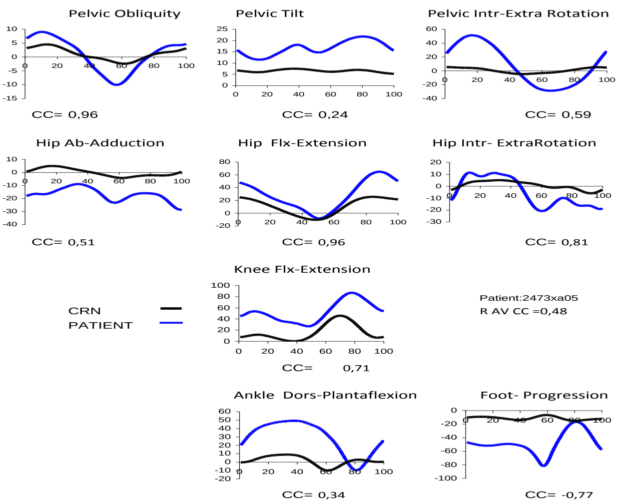

Figure 1: Drawing of 9 SRN curves simultaneously with the patient's curves.

With a single number, the correlation coefficients (CC) allow, the similarities between two curves to represent any physical parameter which varies according to the time or space, independent of the number of samples representing each curve. However, to calculate the CC, the two curves must be represented by the same quantity of samples [1], [2]. The magnitudes of the CC vary between $-1 \leq CC \leq 1$; [2], [3].

If two signals, f(t) and g(t), are plotted simultaneously, a scatter plot or Lissajous figure is obtained. The trend line of the scatter plot has a close relationship with the CC.

The function of probabilistic significance (Zsc) is a function that quantifies the dispersion of each point on a curve expressed in standard deviation [4], [5], [6]. When the CC is at its maximum, the Zsc is minimal, but this inverse relationship is not linear.

A program was developed in Excel to compare the matrix of data from a patient with the matrix of data to a normal subject [6], [7]. All matrices are exported from Elite Clinic's MAL system to an Excel spreadsheet.

This program calculates the CC and the role of Zsc. The program draws SRN curves simultaneously with the patient's curves.

The system plots the data produced by the simultaneous log of the angular curves of the SRN and a patient's respective curves and graphs of the Zsc functions for each joint.

The LRS, which is based on its own bilateral hip and knee JSM, produces flexion-extension angular curves, force curves and moment curves. A log within the system generates 12 kinematic and kinetic curves, with an average of 500 values per cycle, with amplitudes that vary depending on the programmed speed of the JSM (Figure 2).

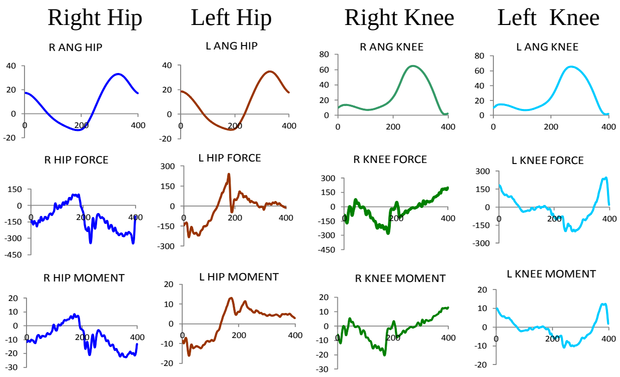

Figure 2: Shows the twelve curves generated by the JSM for a gait cycle in the sagittal plane (4 angular curves, 4 force curves and 4 moment curves).

In Figure 2 symmetry in kinematics angular curves can be observed (left and right hip, and left and right knee), and curves of power and moments are morphologically identical in both hip and knee bilateral joints.

Results

Biomechanical curves were recorded from the LRS with and without patients, with normal subjects and patients, for speeds ranging from 1.5 km/hr and 3.2 km/hr. Changes in walking speed only affect the temporary differences of each cycle, but the morphology of the kinematics curves is preserved.

The CC was calculated between the kinematics angular curves of the hip and the angle of the right and left knee, between LRS and SRN. The results are shown in Figure 3, together with traces of the respective curves, and the value of Zsc.

The angular curves of bilateral LRS hip and knee joints were compared with the corresponding curves of SRN. Figure 3 shows the graph of bilateral simultaneous kinematics angular curves the hip and knee SRN and LRS, along with their respective scatter plots, Zsc curves and their values.

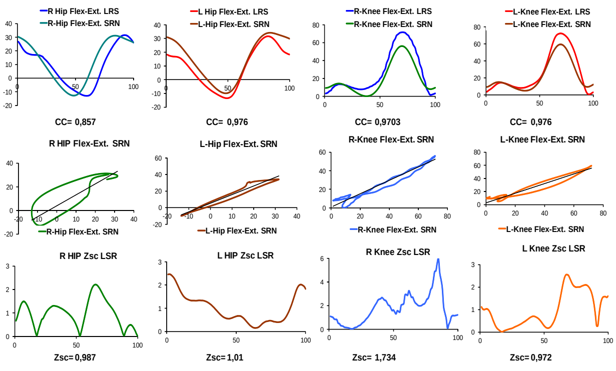

Figure 3: Draws out the angular curves of CRN and LRS of bilateral hip and knee joints in the sagittal plane.

The Table 1 shows the value of CC and average respective of Zsc.

Table 1: Result CC and average Zsc for articular curves

AC	CC SRN vs LSR	Av Zsc LSR
R HIP	0,857	0,987
LHIP	0,976	1,011
R KNEE	0,970	1,734
LKNEE	0,976	0,972

The CC between the angular curves of the hip and knee joints of the LRS, generated maximum values of CC=0.976 (Table 1). Similar CC was obtained and was almost symmetrical in the four kinematics angular curves, with a reduced CC and Zsc values in accordance with expectations.

The CC and Zsc values between the kinetics curves and the moments of the right and left knee and hip, were calculated and are shown in Figure 4, their results in Table 2.

Table 2: Result CC and average Zsc for Moments

MOMENT	CC SRN vs LSR	Av Zsc LSR
R HIP	0,754	2,301
L HIP	-0,384	8,320
R KNEE	0,232	2,503
L KNEE	0,220	2,051

Table 2 shows the value of CC and the respective average of Zsc for moment of LRS compared with respective moments of SRN MAL. The CC between moments of the LRS hip and SRN were less than 0,754 and negative in the left leg (CC= -0.384).

Figure 4 show curves of moments of LRS and SRN, in the hip joint.

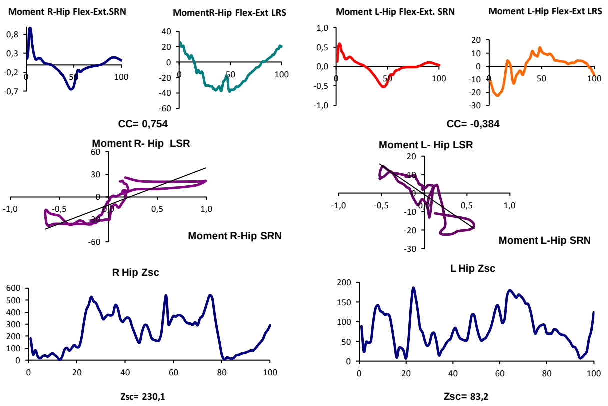

Figure 4: Curves of Moments of SRL were compared with the respective SRN curves of the hip joint.

Figure 5 show curves of moments of LRS and SRN, of the knee joint.

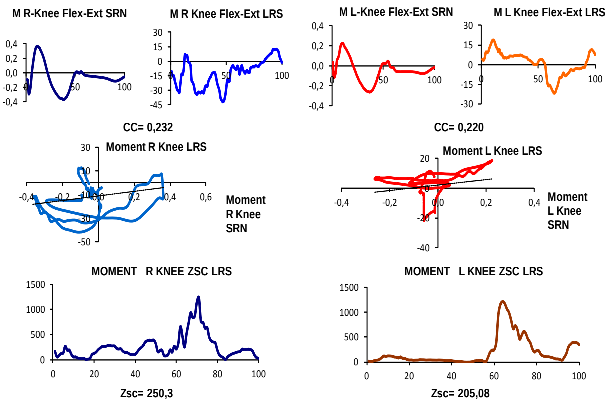

Figure 5: Curves of Moments of SRL were compared with the respective curves SRN of Knee joint.

The model of a gait cycle in the sagittal plane shows the stance phase in the lower perimeter, while the upper shows the swing phase as seen in Figure 6 [8], [9], [10].

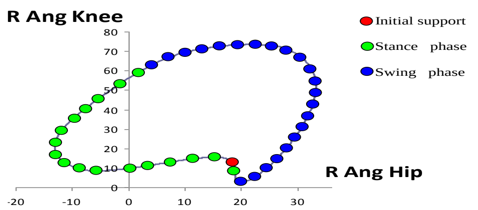

Figure 6: Scatter plots between hip and knee angular curves of both legs generated by the JSM.

Each of these curves represents the average of 20 LRS cycles gait of the legs, at a mid-speed of 2.35 km/hr [10]. A scatter plot is drawn of the sagittal plane using the angular curves from the LRS and data from the SRN bilateral hip and knee joints.

In addition to varying the speed of travel, the LRS allows for the variation of forces or loads generated by the JSM engines in patients when loads decrease from 100% to 50% or 30% (Figure 7).

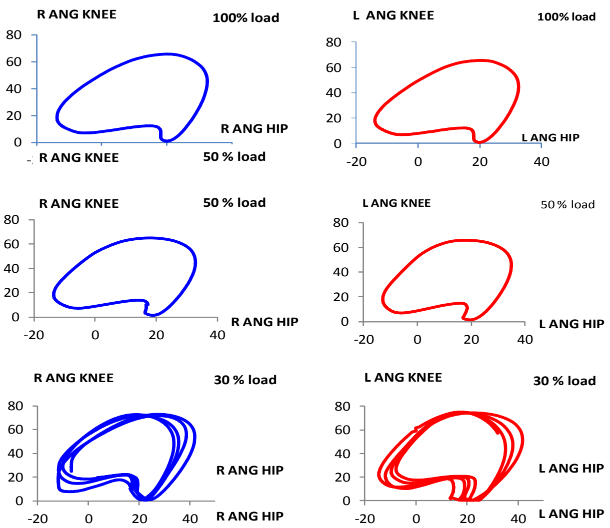

Figure 7: Scatter plots of the relationship between knee and hip angular curves, respectively, for loads of 100%, 50% and 30%.

The scatter plots for loads between 50% and 100% had no significant differences; however, the curves of 30% load show some variations.

Table 3 shows the results of 7 patients randomly selected and treated with the LRS compared with SRN of MAL.

Table 3: CC between LRS SRN of MAL

PATIENT	knee 30%	Knee 50%	Hip 30%	Hip 50%	Force Knee 30%	force Knee 50%	Force Hip 30%	Force Hip 50%
P1 (C, P,)	0,998	0,999	0,987	0,998	-0,023	0,428	0,194	0,619
P2 (G, A,)	0,992	0,999	0,990	0,997	0,448	0,680	0,473	0,609
P3 (J, R,)	0,999	0,999	0,997	0,999	0,216	0,394	0,381	0,434
P4 (L, P,)	0,994	0,999	0,998	0,999	0,35	0,190	-0,002	-0,239
P5 (M, G,)	0,995	0,999	0,999	0,997	0,339	-0,371	0,177	0,203
P6 (F, A,)	0,997	0,999	0,999	0,998	0,509	0,459	0,226	0,200
P7 ((I, M,)	0,999	0,999	0,998	0,996	0,235	0,328	0,139	0,480

The CC was calculated from the angular curves of hip and knee, the CC of force curves between both systems was also calculated, for the right and left average values.

The results in Table 3 show that the CC of angular curves was greater than 0.99 for a force of 50% and 30% in the hip and knee joints, while with the same force and joints the CC of all curves were less than 0.62 and negative (-0,371) for knee force at 50% of power.

Discussion

Figure 3 shows the similarity between the angular curves, with a delay between them. This delay can be measured from the scatter plots between pairs of homologous curves. A larger delay generates a larger area in the scatter plot. The points of scatter plots are distributed around a trend line. These characteristics (delay, dispersion area and trend line), are related to the CC in some way. A Zsc graph represents the set of individual Zsc values of each point in gait cycle, which has been standardized on 100 points.

The results in Table 1 represent the values of CC between the angular curves of hip and knee joints of both legs, generated by the LRS and homologous curves of SRN, and the respective values average Zsc in one gait cycle.

The CC values between the moment curves, according to Table 2, were below the CC of the angular curves. But averages Zsc were higher than those of the angular Zsc curves. The inverse relationship between CC and Zsc is checked, but this inverse relationship is not linear when working with average Zsc.

Plotting simultaneously, for example, right hip angular curve (x axis) and the angular bend of the right knee (y axis) of LRS, the dispersion diagram of Figure 6 is obtained. Figure 7 depicts these same diagram dispersion obtained from LRS during treatment of a patient. The load given to JSM ranged from 100% to 50% and 30%.

Table 3 shows the values of CC between the right and left sides of the knee and hip angular curves , and the value of CC between knee and hip forces curves for 30% and 50% loads, values reordered from seven patients treated with LRS. The CC for knee and hip angular curves were maximum, regardless of the force applied to the LRS joint servomechanism. However, the CC curves of joint forces were much lower.

This difference is attributed to the action of the leg biomechanism of patients, as opposed to the legs of the LRS, when loads on the JSM were down by 50% to 70%. These changes are reflected graphically in 30% loads, according to figure 3, wherein the scatter diagrams are shifted during the simultaneous graphic representation of several cycles of operation.

Conclusion

This study finds that the LRS used with patients suffering from gait disorders is adequate. The result shows that the cinematic curves of LRS are very similar to the cinematic curves generated by normal subjects. However, the kinetics curves (force and moment), have no similarities, because the application points of JSM forces differ from the muscles' insertion points. The arms' moments are also different.

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