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CLASSIFICATION OF PATIENTS WITH FEMOROACETABULAR IMPINGEMENT USING PELVIS AND HIP ANGULAR DISPLACEMENT DURING GAIT

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SUMMARY
The aim of this study was to develop a classifier, using multilayer perceptron neural networks (MLP), on subjects with femoroacetabular impingement (FAI), based on the pelvis and hip angular displacement during gait. The gait of 18 subjects (nine in the control group and nine in the FAI group) was collected and the kinematics calculated. Principal component (PC) analysis was applied to reduce the dimensionality of the 3D angles of the pelvis and hip during a gait cycle and the Standard Distance (SD) was calculated based on the PC scores. The SD data for each of the three planes in the pelvis and in the hip were compared between the two groups and the variables that showed significant differences were used in the model. The results indicated that the displacements in the transverse plane of the pelvis and the three planes in the hip differ between the two groups. Therefore, these variables were entered into the neural network model. The MLP model showed a good performance (0.95 area under curve and 0.89 accuracy) and was considered adequate to identify patients with advanced degree of FAI; this may assist medical decisions regarding the need for surgical treatment.

INTRODUCTION
Recent studies support the hypothesis that the primary osteoarthritis is, in fact, secondary to subtle abnormalities in the hip development. The etiopathology in most of the cases are the femoroacetabular impingement (FAI), and not only the overload placed in the joint or genetic tendency [9]. Despite its high incidence of suggestive signs in image exams the decision making for surgical treatment is mostly based upon clinical criteria.

The development of tools to support the decisions based on algorithms that automate this process would be useful to assist surgical indications and assess outcomes.

A variety of activities can cause or increase hip pain in people with FAI such as prolonged sitting or excessive walking. Gait is the most common repetitive voluntary movement humans perform. Therefore, the aim of this study was to develop a classifier of subjects with femoroacetabular impingement (FAI), based on gait parameters.

METHODS
The FAI group consisted of nine subjects with unilateral changes in the hips, with X-Ray and MRI images showing degenerative changes in the acetabular rim and femoral neck, and clinical diagnosis of FAI-type cam, pincer or mixed as suggested by Leunig et al. [9]. The criteria for inclusion in the FAI group were to present pain in the hip region while loading, decreased range of motion of the hip due to mechanical friction and positive signs of FAI in image exams. Exclusion criteria were to present any neurological abnormalities. A matched control group (CG) was composed of nine healthy subjects with no history of injury and pain in the lower limbs or presence of neurological abnormalities, and presenting scores greater than 90 in the Lower Extremity Functional Scale [10].

Subjects walked seven times at a self-selected speed along an 8 m walkway. The first four laps were not measured to allow familiarization with the task and instrumentation. The last three laps were evaluated to determine the lower limb kinematics during three gait cycles, using the right lower limb in the CG group and the injured limb in the FAI group.

Reflexive markers were positioned on the skin according to the Helen Hayes marker set. The motion analysis system (MaxPro version 1.4.2.1, INNOVISION Systems, USA) was composed of four cameras; the sample rate was set at 60 Hz. The 3D coordinates were filtered by a 2^{nd} order, zero lag, low pass Butterworth filter, with cutoff frequency of 6 Hz. After filtering, local coordinate systems for each segment were determined and the 3D angles of hip were calculated according to ZXY sequence [6]. Pelvis angles were calculated using the ROT sequence proposed by Baker [1]. To detect the initial ground contact, the Foot Velocity Algorithm (FVA) was used [11]. Each gait cycle was interpolated to 51 values by a Cubic Spline Algorithm.

For statistical analysis, initially the angular data of the pelvis and hip of two groups at each gait cycle were inserted into six different matrices **D** [54 x 51], where each line corresponded to an individual gait cycle and each column to angle values. Three gait cycles of each subject were included in each matrix of each subject in order to represent the intercycle variability of individual kinematic data. Therefore, the mean of each column was subtracted and the covariance matrices **S** [51 x 51] calculated. Principal component (PC) analysis was applied to each of these matrices **S**, separately [7]. The number of PC retained in the analysis from each matrix was those that the cumulative sum accounted approximately 85% of the original data variance. The standard distance (SD) [5] from each kinematic variable was calculated using the retained PC scores.

To develop the multilayer perceptron neural networks (MLP) the data set was randomly partitioned into three sets, called training, testing and validation groups, containing 60%, 20% and 20% of the gait cycles, respectively. The six initial variables were compared between the two groups (unpaired t test, $\alpha = 0.05$) to determine which should be inserted into the MLP model. The variables that showed significant differences were re-scaled to fit the range [-1, 1]. In both layers of the MLP, the hidden and the output, the activation function used was the hyperbolic tangent.

The number of neurons in the hidden layer was chosen by testing the performance of networks with different sizes, always seeking models with few hidden neurons and with good generalization power. The Levenberg-Marquardt Backpropagation algorithm was used to train the network. To avoid overfitting, the generalization error obtained for the validation set during the training process and the minimum gradient were used as the stop criteria. It was used 5000 training epochs.

To assess the performance of the classifier, the following parameters were used: area under the ROC curve (AUC); accuracy (Acc); sensitivity (Sens); Specificity (Spec). These values were calculated based on 1000 bootstrap samplings, using the 0.632+ method [4]. The negative likelihood ratio (NLR), and the positive and negative predictive values (PPV and NPV, respectively) were also calculated. All data were processed using Matlab 7.8.0 (The Mathworks, USA).

RESULTS AND DISCUSSION

The present study was aimed to create a classifier of the gait from femoroacetabular impingement patients, having as parameter the normal gait pattern of healthy subjects. Neural network models were used to find nonlinear relationships between the variables and develop more robust models than other techniques able to find only linear relationships, such as logistic regression [3].

To select which variables should be entered into the model, it was used initially an exploratory data analysis and applied Student t tests for identifying differences between the two groups. The Student t test showed differences in both pelvis (transverse plane) and hip (sagittal and transverse planes), with values near to normality in the frontal plane. The averages, confidence intervals and p values of the SD for each plane of movement are shown in table 1.

Other studies have found similar results to those found in this study [2,8,12]. It is proposed that changes in the hip joint are related to joint stabilization strategies to prevent pain while the changes in the pelvis seem to be related to restricted mobility of pelvic joint lumbosacral [2,8,12]. Based on these results, the variables included in the model were the SD of pelvis in the transverse plane and SD of the hip in all three planes.

The model was tested with three, four, five, six and nine neurons in the hidden layer. In all conditions, the classifier converged to the minimum stipulated error. However, the model with three neurons showed the best results over all measurements. Therefore, seeking a more parsimonious classifier, we chose to keep three neurons in the hidden layer.

To complete the analysis, each variable initially included in the model was removed, one by one, and the classifier was trained to determine the effect of the withdrawal on the performance of the classifier. Independent of the removed variable, the classifier performance was worse than with all four initial variables. Therefore, the four variables were maintained in the model. Finally, the final classifier based on MLP neural networks showed the following performance parameters: AUC: 0.95; Acc: 0.89; Sens: 0.89; Spec: 0.88; NLR: 0.15; PPV: 0.89, NPV: 0.88.

CONCLUSIONS

The MLP model of patients with FAI showed a good performance and the classifier was considered adequate to identify patients with advanced degree of FAI, assisting medical decisions regarding the need for surgical treatment.

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Table 1: Mean of the Standard Distance (CI 95%) for each plane of movement.

Variables	Control group	FAI group	p value
PS	0.76 (0.51 – 1.01)	0.57 (0.36 – 0.78)	0.240
PF	1.25 (1.01 – 1.49)	1.53 (1.27 – 1.80)	0.117
PT	1.48 (1.14 – 1.82)	2.59 (2.17 – 3.01)	<0.001
HS	1.26 (1.03 – 1.49)	1.95 (1.44 – 2.46)	0.016
HF	0.80 (0.57 – 1.03)	0.55 (0.41 – 0.70)	0.067
HT	1.50 (1.17 – 1.82)	3.06 (2.11 – 4.01)	0.003

PS: pelvis in the sagittal plane; PF: pelvis in the frontal plane; PT: pelvis in the transverse plane; HS: hip in the sagittal plane; HF: hip in the frontal plane; HT: hip in the transverse plane.