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Experimental measurement of flexion-extension movement in normal and osteoarthritic human knee

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Abstract

The paper presents a comparative experimental study of flexion-extension movement in normal and osteoarthritic human knee. Measurements were performed on a group of seven healthy subjects and on a group of five patients with OA knees, for which experimental data were acquired for walking cycles on treadmill. Using an electrogoniometer-based acquisition system, the data were collected during the experimental gait on a treadmill with the speed equal to 3.6 km/h. The flexion angle during the gait cycle revealed differences with respect to flexion magnitude between the OA patients and the healthy subjects group. Statistical analysis demonstrated that the knee flexion angles were significantly different for experimental measurements of the OA patients' knees and healthy knees, but, also, the healthy knees of the patients were on average less flexed than gait cycle of the healthy subjects.

Keywords: gait analysis, knee osteoarthritis, electrogoniometer-based acquisition system, treadmill.

⎐ Introduction

Musculoskeletal disorders are the most frequent cause for long-lasting or chronic pain and for restrictions on physical performance and can lead to constraints on mobility, to long-term disability and, in the extreme case, to an increased morbidity. Musculoskeletal disorders affect hundreds of millions of people worldwide with dramatic increases expected due to a doubling in the number of people over 50 years of age by 2020 [1].

Osteoarthritis is the fourth most frequent cause of health problems in women and the eighth most frequent cause in men. About 40% of all men over the age of 70 years are affected by osteoarthritis of the knee, about 80% of patients with osteoarthritis suffer from limited mobility, and 25% of these patients can no longer perform the most important basic activities of daily life. Fifty percent of patients suffering from rheumatic arthritis must quit their employment within 10 years of the disease onset [1].

The knee osteoarthritis is one of the major chronic diseases usually found in people of middle age and old age and also mainly causes various disabilities. Knee osteoarthritis involves a degenerative process of cartilage in the knee joint leading to its loss [2].

This degenerative process can be generally caused by obesity [3], by excessive physical activity, by joint trauma, immobilization and the hypermobility [4]. Level of disability caused by osteoarthritis is comparable to that of heart failure or end-stage kidney diseases [5]. Knee misalignment is considered one of the biomechanical key factors, factors that influence the progression of knee osteoarthritis [6]. Purpose was to observe the effect of the frontal plane tibio-femoral alignment on the overall stress and strain within the knee joint during the stance phase of the gait cycle and single leg stance.

Gait analysis is a modern tool that offers the possibility of measuring the biomechanical response to diseases of the musculoskeletal system, such as knee osteoarthritis (OA). The volume of data gait analysis is multidimensional and correlated. It is very important for the gait analysis and for the use of the results to clinical analysis to reduce the large volume of experimental collected data [7]. One of the simplest methods of analyzing gait data is the definition and extraction of parameters (*i.e.*, ranges, peak values) as descriptors of discrete instants or events of the gait pattern [8–10]. The waveform analysis techniques include qualitative comparison and subjective descriptions of the overall shapes of gait waveforms [9, 11, 12]. Quantitative analysis methods of the entire gait cycle data include Fourier series, neural network classifiers, and pattern recognition techniques [13–15].

In [7], Chau T presented a review of analytical techniques for gait data. In [5] the principal components waveform analysis technique was used as a data reduction tool in a comparison of the gait patterns of a group of patients with end-stage knee osteoarthritis and of a control group. The objective of the paper was to determine the biomechanical features of these gait measures that are related to knee osteoarthritis. The range of knee flexion in the sagittal plane (knee flexion angle) as well as peak flexion angles is generally lower in patients with knee OA. The importance of the range of knee motion in the sagittal plane to knee osteoarthritis has been identified in previous gait analyses [8–10, 16]. Generally, the human joint movement data are collected with different

acquisition systems, are extracted, analyzed and are represented as temporal diagrams representing specific joint measures during the gait cycle [16–20].

The aim of this paper is to compare the range of motion and the amplitude of the flexion-extension knee for a healthy subjects group and for a patients group with OA knees.

⊟ Materials and Methods

Subjects

The knee flexion angle was chosen for investigation in this study because their importance to knee osteoarthritis was identified by previous investigators [5].

Measurements were performed on a group of seven healthy subjects, all men, and aged between 27 and 33 years, for which experimental data were acquired for walking cycles on treadmill. They were pain-free, without any evidence or history of arthritic disease, or record of surgery to the lower limbs. The study was approved by the Human Ethics Research Committee, University of Craiova, Romania. The osteoarthritis patient group consisted of five patients with knee osteoarthritis, who were prior evaluated in the first or second stage of OA.

Before starting, the experiments there were collected anthropometric data both from healthy subjects and from subjects with OA. In Table 1, the mean values and standard deviations for anthropometric data of healthy subjects are displayed (presented) and in Table 2 are displayed the mean values and standard deviations for anthropometric data of subjects affected by OA.

Table 1 – *Mean values and standard deviations of anthropometric data from healthy subjects*

Subject	Age [years]	Weight [kg]	Height [cm]	Leg length [cm]	Hip–knee length [cm]	Knee–ankle length [cm]
Average	31.57	77	174.71	85.286	45.28	40
St. Dev.	4.27	6.63	4.27	6.5	4.75	1.91

Table 2 – *Mean values and standard deviations of anthropometric data from patients with OA*

Subject	Age [years]	Weight [kg]	Height [cm]	Leg length [cm]	Hip–knee length [cm]	Knee–ankle length [cm]
Average	52.4	80.6	173.2	83.2	44.4	38.8
St. Dev.	4.04	15.71	10.26	11.58	6.66	5.36

To each subject it was presented in advance the development of each test protocol. The subjects become familiar with the tests by repeating them several times before the beginning of the final experimental test.

Description of the experimental tests

For healthy persons, the experimental test was performed in the Biomechanics Laboratory at the Faculty of Mechanics, University of Craiova. This test consists of walking on treadmill for three minutes at a speed of 3.6 km/h. For the suffering subjects, the experimental test consisted of walking on treadmill for one minute at a speed of 3.6 km/h. This test was performed in the recovery room at the Department of the Emergency Physiotherapy, Emergency County Hospital of Craiova.

Equipment

For collecting the experimental data occurred during testing, we used a data acquisition system, which is based on the use of electrogoniometers, which aim to determine the interval of variation of the knee joint angle formed by the femur and tibia during walking [20]. An electro-goniometer is composed of two duralumin rods, each of these rods being equipped with two mounting holes. The grip of these rods is made on the femur, respectively on tibia, using Velcro type elastic fastening straps. On the joining of these two rods, a potentiometer (Vishay Sfernice P11L) is mounted in a cylindrical chamber.

The potentiometer is attached on the fixed rod (united with the femur) with a nut, and the mobile rod is being attached with a bolt on the potentiometer head and can provide a maximum course of 270^0. A course limitation is possible if a locking system for both directions of motion is used.

The acquisition system consists of two electro-goniometers, one for each leg, for making possible to simultaneously read data during walking (Figure 1).

Figure 1 – *Fixation of the two electro-goniometers on the lower limbs.*

These two potentiometers connect to data acquisition and control Arduino Mega 2560 plate. This plate aims to collect information from both potentiometers and to return this information on the computer screen from where it can be stored and processed afterwards in order to obtain graphs and diagrams featuring the physical process. The Arduino Mega 2560 acquisition board is attached to the femur using a Velcro strip. The information is transmitted to the computer *via* a Bluetooth conveying device. In this board is loaded a code written in C/C++, which returns the values for angles depending on time.

⊟ Results

The angular amplitudes of human knee flexion-extension during the gait performed on the treadmill were obtained for each healthy person from the report generated by the acquisition system based on electro-goniometer, as data files.

The diagrams of the knee flexion-extension angles of Subject No. 1 collected for several walking cycles using the acquisition data system for both legs (right and left) are shown in Figure 2. In Figure 3 is presented one walking cycle of the right knee.

In order to reduce the noise, the *.xls* data files type

were filtered. The filtered diagram of the knee flexion-extension angles of Subject No. 1 for the right leg is shown in Figure 4. Next, all data was processed in Excel and MATLAB environment and evaluated.

The knee flexion-extension movements occur entirely within the normal range of motion according to normative data.

For more accurate results, considering the natural biological variability from one's individual step to another, but also from one individual to another, for each healthy subject were selected 15 consecutive steps, which were normalized by interpolation with cubic Spline functions, using MATLAB environment, and reported on the abscissa at a scaled interval from 0 to 100%. The average footstep was determined as being the data's arithmetical mean that correspond to the 15 steps.
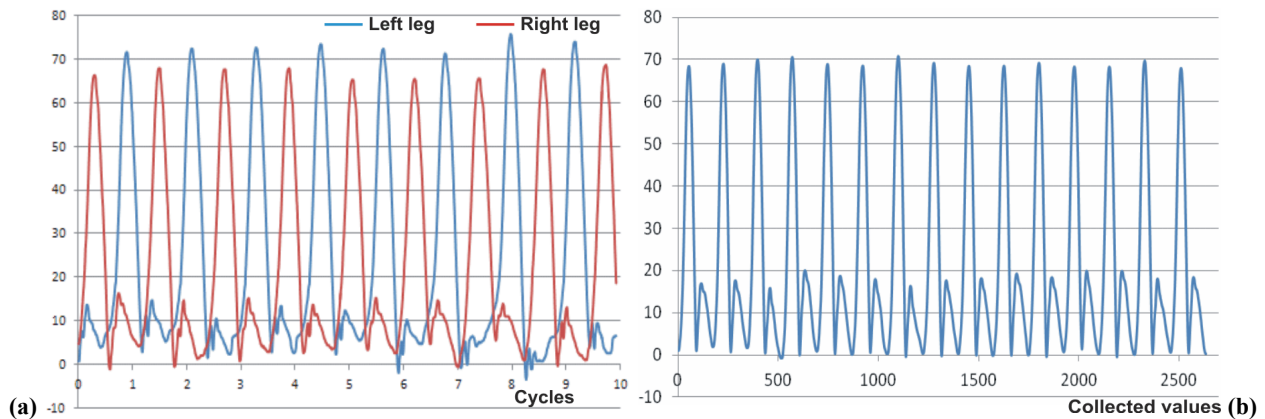
For each subject were drawn the curves of flexion-extension angles corresponding to each step, and also it has been drawn the corresponding curve of the medium step. In Figure 3, there are being displayed the curves of the 15 steps recorded on the treadmill at the speed of 3.6 km/h and the medium step corresponding to Subject No. 1.

The corresponding mean curves of flexion angles with respect to the time for each subject and the final medium step curve are shown in Figure 4, where Subject No. 1– Subject No. 7 represent the mean step curve of the seven healthy subjects on the treadmill.

In a similar manner, is determined and graphically represented afterwards the medium step for the treadmill test at a constant speed of 3.6 km/h for the OA patients for both cases: the OA affected knee (Figure 5), and the healthy knee (Figures 6).

Figure 2 – *Subject No. 1: (a) Walking cycles of the right and left knees on the treadmill at 3.6 km/h; (b) Fifteen walking cycles of the right knee on the treadmill at 3.6 km/h.*
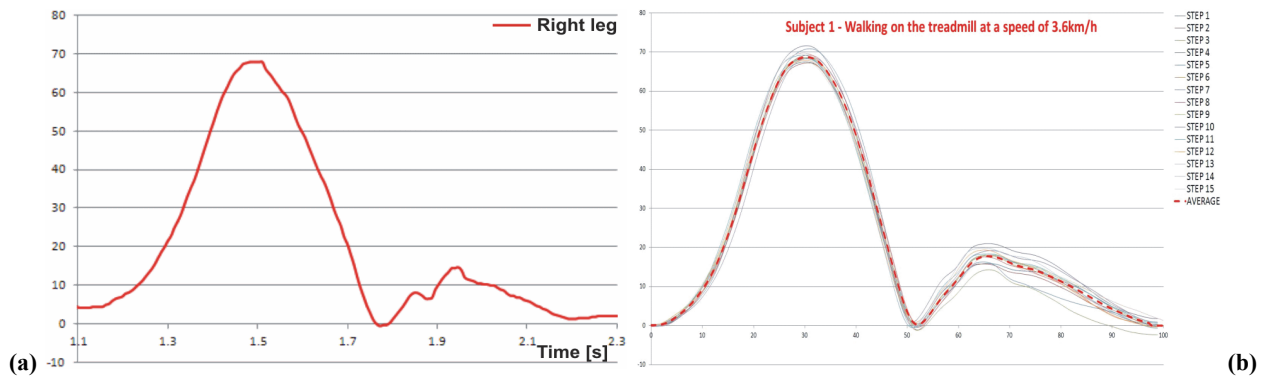

Figure 3 – *(a) Subject No. 1: one walking cycle of the right knee on treadmill at 3.6 km/h. (b) The 15 steps and the medium step for Subject No. 1 at a speed of 3.6 km/h on treadmill.*
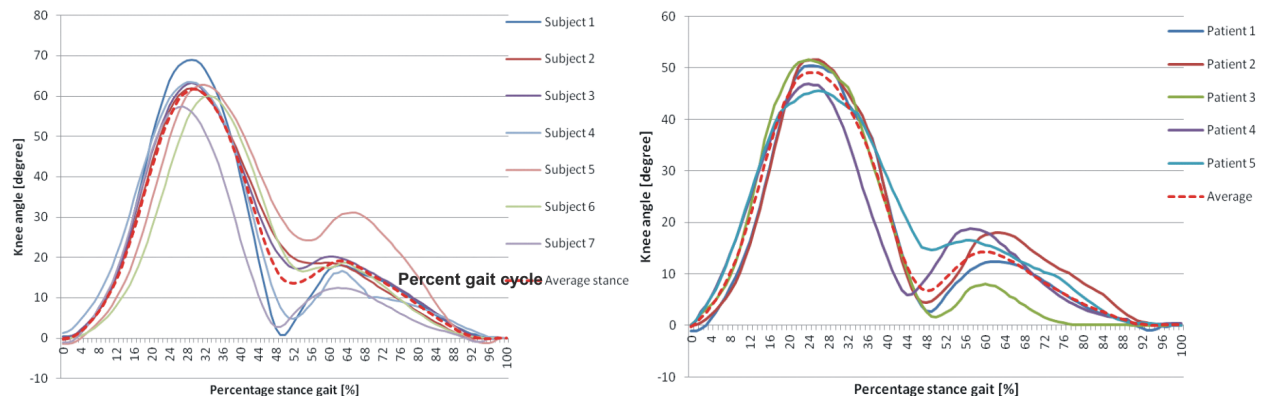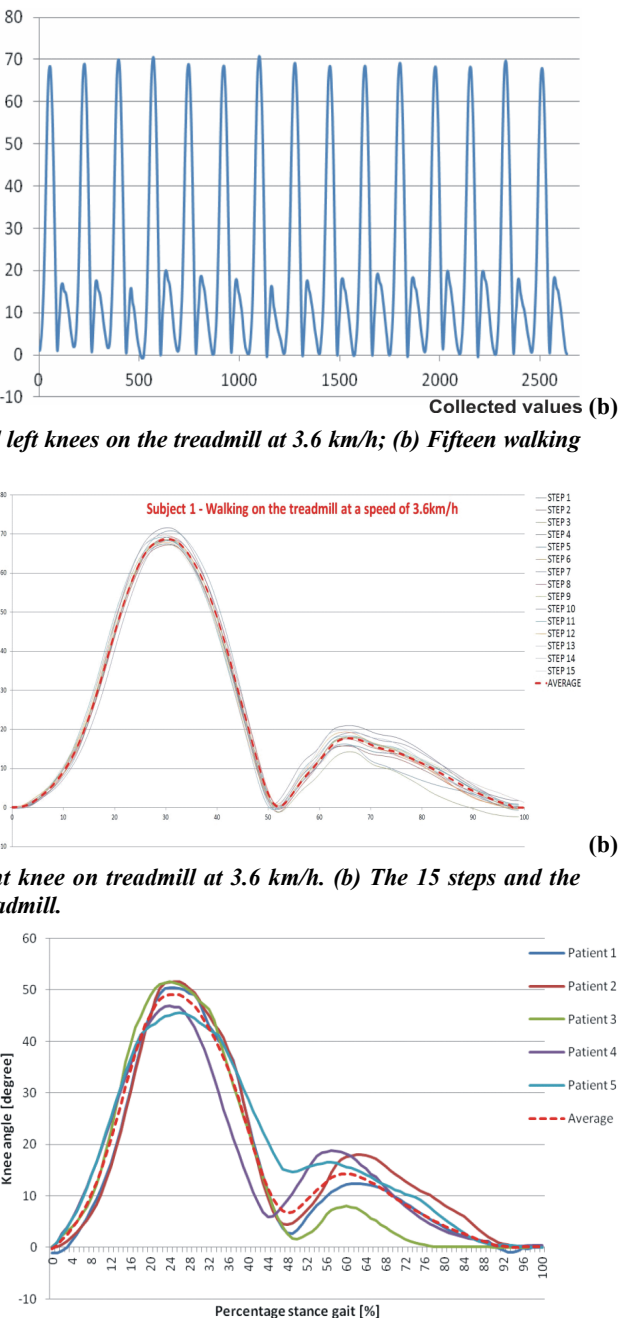

Figure 4 – *Medium step curves for seven subjects and final medium step.*

Figure 5 – *Medium step curves of the OA knee for five patients and final medium step.*
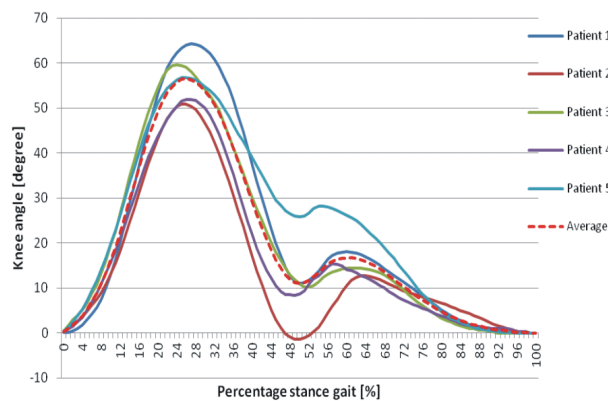
Figure 6 – *Medium step curves of the healthy knee for five patients and final medium step.*

Figure 7 – *Medium step for healthy subjects, for OA knee and normal knee of the patients.*

⊟ Discussion

Comparing the 15 maximum amplitudes of the knee flexion for the healthy Subject No. 1, the values ranged from 67.22^0 to 71.61^0 and the mean value was 68.76^0, with a variation of the standard deviations between 0.131^0 to 4.363^0. The values of the medium step were calculated as average of the 15 steps values. The maximum amplitude of the medium step was 68.67^0, very close to 68.76^0 with non-significant differences. The minor differences obtained by this comparison show a good repeatability of the imposed exercise for Subject No. 1. All the subjects also performed the test with a good repeatability.

When comparing the knee maximum amplitudes of the healthy subjects, the values ranged from 57.38^0 to 69.01^0 and the mean value was 62.56^0. For the patients, the maximum amplitudes ranged from 45.53^0 to 51.73^0 and the mean value was 50.47^0 for the OA knee. For the healthy knee of the patients, the maximum amplitudes ranged from 50.86^0 to 64.23^0 and the mean value was 50.47^0.

The maximum values of the knee angle for the seven healthy and for the OA knee of the five patients determined during the performed trials were compared and tested with an unpaired Student *t*-test, considering $\alpha=0.05$. The *p*-values corresponding to these tests are calculated using ANOVA.

The maximum flexion angles were significantly different ($t_{calc}=7.217>t_{cr}=2.228$ and $p=0.000051<0.05$) for the two studied cases.

In a similar manner, we can conclude that the maximum flexion angles were significantly different ($t_{calc}=2.646>t_{cr}=2.228$ and $p=0.0388<0.05$) for the healthy knees and for the OA knees of the patients. The maximum flexion angles were not significantly different ($t_{calc}=2.09<t_{cr}=2.31$ and $p=0.0785>0.05$) for the healthy knees of patients and of healthy subjects.

The flexion angle during the gait cycle revealed differences with respect to flexion magnitude between the OA patients and the healthy subjects group (Figure 7). There were not big differences in the shape of the flexion angle. The OA subjects had less range of motion during the gait cycle than the healthy subjects. A large difference between the amplitude of knee flexion during 25–50% of gait cycle phase and 65–80% of gait cycle phase is revealed.
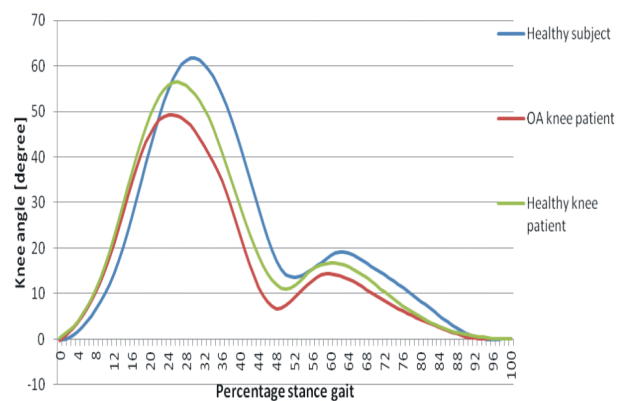
The statistical analysis revealed that the OA patients' knees were on average less flexed throughout the gait cycle than the healthy subjects were ($p=0.000051$), but, also, the healthy knees of the patients were on average less flexed than gait cycle of the healthy subjects. This is explained by the influence of the OA knees pain and by body tendency of maintaining the stability when reaching the knee flexion amplitude.

⊟ Conclusions

The study presents a comparison based on the experimental data collected for healthy subjects and for OA affected patients during the gait on the treadmill at a speed equal to 3.6 km/h to identify the importance of knee flexion range of motion. An electrogoniometer based acquisition system was considered to collect the data files. Statistical analysis demonstrated that the knee flexion angles were significantly different for experimental measurements of the OA patients' knees and healthy knees. For further work, we intend to study differences in gait across the spectrum of disease severity. Some of the differences we observed in the flexion angle amplitude could be due to the walking speed. Therefore, the effect of speed on gait biomechanics for the normal knee and OA knee will be studied in the future work.

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