Experimental study of sit-to-stand kinematics in healthy, osteoarthritic and prosthetic knee

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Abstract. The purpose of this study was to evaluate changes in movement patterns during a sit-to-stand (STS) task before and after total knee replacement (TKR), the impact of the prosthesis on the kinematic parameters of sit-to-stand flexion movement and to compare biomechanical outcomes after TKR to a control group. A sample of seven healthy control subjects and five patients suffering of knee osteoarthritis (KOA) participated in three-dimensional motion analysis. Although there were significant improvements in movement 4 months after TKR, patients continued to demonstrate smaller moments on the prosthetic knee compared to non-operated and to control knees.

1. Introduction

Human movements are the most bioinspired movements applied for the design of humanoid robots, advanced prosthetic limbs, rehabilitation devices such as orthotic devices or exoskeletons used for medical applications, especially in the rehabilitation of pathological gait, and robotic structures used in minimally invasive surgery [1-20].

Standing up from a seated position is an essential condition for walking and therefore for the functional independence of an individual [21-23]. The mechanical difficulty of the STS movement is likely to present a substantial challenge to population groups with reduced muscle strength [22], with high chance of instability and a higher risk of falling as the body rapidly changes from a stable seated position to a position with a relatively small base of support and a higher centre of mass [24]. Considering the difficulty of the task and its importance to mobility, the STS movement is relevant for people involved in rehabilitation.

However, for individuals with compromised mobility the STS movement can be problematic [25-27]. It has been reported that people who have difficulties in standing up from a seated position are more likely to fall during walking [28-30]. The inability to stand was related to death among the elderly people [29-31]. Standing-sitting on a chair is a complex biomechanical daily activity that involves the movement of all body segments. In order to stand up from the chair a person needs, at the same time, sufficient mobility, the strength of the lower limbs (force generation capacity) and the balance to allow the center of the mass to move forward and upward from the stable seated position in the orthostatic position (standing) on a small support base [29]. When standing from the chair it is necessary to develop adequate torques in each lower limb joint to maintain the stability of the person by locating the vertical component of the reaction force with the ground in the support area.
Osteoarthritis of knee (OAK) is an important chronic disease of middle aged and elderly people and one the most common joint disease affecting 30% of adults over 50 years of age [34]. Depending on the stage of cartilage degradation, OAK is unstable, lax and affects the entire lower limbs’ movements. It can be caused by various factors: misalignment, injury, joint trauma, immobilization and the hypermobility genetics and obesity and it involves a degenerative process of femoral and tibial cartilages of the knee joint [35–38].

The purpose of the standing-sitting experimental test is to compare the variation range and the amplitude of the flexion-extension angle for the knees of the subjects in the healthy sample and for the osteoarthritic knee of the patients before Total Knee Replacement (TKR) and after TKR surgery. The influence of TKR surgery on the osteoarthritic knee on the flexion-extension movement is studied.

2. Experimental protocol

2.1 Subjects

Measurements were performed on a sample of 9 healthy subjects without pain or musculoskeletal disorders and a sample of 5 patients with a high degree of osteoarthritis in one knee. In the case of patients, the measurements were made before the total knee replacement (TKR) surgery and after 4 month from TKR. The Ethics Committee of the University of Craiova approved the research. Tests performed by healthy subjects were conducted in the Biomechanical Research Laboratory of the Research Platform of the University of Craiova, INCESA, while the patients performed the tests in the Department of Orthopedics-Traumatology of the Emergency County Hospital of Craiova. The tests were performed the day before the TKR surgery, and 4 months later in order to analyze the evolution of the patients and the impact of the prosthesis on the kinematic parameters of sit-to-stand flexion movement. In Table 1 and Table 2 the mean values and standard deviations for anthropometric data of healthy subjects and of patients affected by OA are presented.

Table 1. Mean values and standard deviations of healthy subjects’ anthropometric data

|       | Age [years] | Weight [kg] | Height [cm] | Leg length [cm] | Hip–knee length [cm] | Knee–ankle length [cm] |
|-------|-------------|-------------|-------------|-----------------|----------------------|------------------------|
| Average | 30.26       | 75.6        | 172.54      | 83.53           | 44.03                | 39.5                   |
| St. Dev. | 3.73        | 6.18        | 4.12        | 4.37            | 3.14                 | 2.59                   |

Table 2. Mean values and standard deviations of OAK patients’ anthropometric data

|       | 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                   |

2.2 Equipment

The data gathering and processing system used is the Biometrics system [39, 40], which is commonly used for dynamic motion analysis, in research, medical bioengineering, traumatology, prosthesis, as assessment systems and in clinical rehabilitation programs, as well as in sports medicine and sports performance. This system is complete package of static and dynamic measurement sensors and instruments useful in clinical activities, research centers, or any location away from the biomechanics laboratory, such as a workplace or gym or medical recovery, or a sports ground. DataLOG MWX8 is the equipment developed by Biometrics Ltd to monitor and gather data outside the lab. It allows data gathering both in analogue and digital format by connecting a transfer cable connector to one of the 8 channels of the DataLOG and the second transfer cable connector to the electrogoniometers which are sensors used to study the biomechanics of human joints.
The equipment used during the tests consists of the following components (Figure 2):
- 2 electrogonometers SG 110 (Biometrics Ltd), mounted with the purpose of measuring the angles of flexion-extension angles of both ankle joints;
- 4 electrogonometers SG 150 (Biometrics Ltd), mounted with the purpose of measuring flexion-extension angles in the knees and hips joints;
- 2 DataLOG (Biometrics Ltd UK), for the 6 electrogoniometers.

In Figure 3 is a schematic diagram for the experimental determination of the angle $\Phi$ of the knee, according with the system acquisition schedule Biometrix.

$$\phi = \pi - \alpha$$
$$\phi = \alpha_1 + \alpha_2$$

Figure 1. Equipment DataLOG MWX8.

Figure 2. Components of the equipment.

Figure 3. Schematic diagram for the experimental determination of the angle $\Phi$ of the knee.
2.3 Results
All people in the experiment executed 20 consecutive standing-sitting cycles.

The data files containing the angular amplitudes of both movements of each lower limb joint, in sagittal plane and in frontal plane, were obtained during the sit-to-stand movement for each person from the report generated by the acquisition system. In Figure 4 are presented consecutive cycles of the bending angles corresponding to the repeated sit-lift movements extracted from the seat as files from Biometrics for both lower limbs.

For more accurate results, given the natural biological variability from one movement cycle to another, but also from one individual to another, fourteen consecutive sit-to-stand cycles were selected for each subject, eliminating the first three and last three cycles. These reduced data files were introduced into the SimiMotion software and were normalized by interpolation and reported on the abscissa at a scaled range of 0 to 100%.

![Figure 4](image.png)

**Figure 4.** The consecutive cycles of the bending angles corresponding to the repeated sit-lift movements.

For each subject, the normalized curves of the flexion angles corresponding to each of 14 cycles, as well as the curve corresponding to the mean cycle were obtained. In Figure 5, the curves obtained for
patient 1 by using SimiMotion software are shown. Similar diagrams were obtained for all patients and for all healthy subjects.
Figure 5. Mean cycle of standing-sitting on the chair for: a) right ankle; b) right knee; c) right hip; d) left ankle; e) left knee; f) left hip.

The range of the maximum values of the 14 cycles and the maximum value of the mean cycle of each subject are shown in Table 3, while for the patients they are presented in table 4 (before TKR surgery) and in table 5 (4 months after TKR surgery).

Table 3. Variation intervals of the maximum mean cycle values and the mean cycle maximum value of flexion angle when standing-sitting on the chair for normal right knee of each subject

|                  | Subject 1 | Subject 2 | Subject 3 | Subject 4 | Subject 5 | Subject 6 | Subject 7 | Subject 8 | Subject 9 |
|------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum value range of cycles | 101.46-110.73 | 100.25-104.48 | 96.57-99.58 | 101.32-104.98 | 97.36-98.85 | 96.38-99.14 | 100.29-103.17 | 100.43-102.64 | 99.63-102.17 |
| Max values for mean cycle | 104.28 | 103.14 | 98.36 | 103.65 | 97.92 | 98.06 | 101.82 | 101.56 | 100.35 |

Table 4. Variation intervals of the maximum mean cycle values of each patient and the mean cycle maximum value of flexion angle when standing-sitting on the chair for osteoarthritic knee (right knee) of each patient

|                  | Patient 1     | Patient 2     | Patient 3     | Patient 4     | Patient 5     |
|------------------|---------------|---------------|---------------|---------------|---------------|
| Maximum value range of cycles | 81.35-83.23 | 81.68-84.44 | 80.46-82.84 | 80.28-83.53 | 80.34-82.14 |
| Max values for mean cycle | 82.13 | 82.45 | 81.72 | 82.25 | 80.76 |
Table 5. Variation intervals and maximum value of the maximum mean cycle of flexion angle during stand-to-sit for patients’ prosthetic knee

| Patient   | Maximum value range of cycles | Max values for mean cycle |
|-----------|-------------------------------|---------------------------|
| Patient 1 | 89.82-93.46                   | 91.73                     |
| Patient 2 | 88.24-93.33                   | 92.56                     |
| Patient 3 | 89.77-94.56                   | 93.93                     |
| Patient 4 | 84.78-90.26                   | 88.64                     |
| Patient 5 | 87.42-89.16                   | 88.92                     |

In Figure 6 are presented the sample’s mean cycles of flexion-extension angle, corresponding to stand-to-sit and sit-to-stand test for a) the healthy knee, b) the osteoarthritic knee (before TKR surgery), c) the prosthetic knee (4 months after TKR surgery).

Figure 6. Mean flexion cycle at sample level, corresponding to standing-sitting test for a) the normal knee; b) the osteoarthritic knee (before TKR surgery); c) the prosthetic knee (4 months after TKR surgery).

3. Discussions

The minor differences obtained by comparing the shape and the amplitude of the consecutive cycles show a good repeatability of the experimental test required for the healthy subjects and for patients. There were no great differences in the shape of the knee flexion-extension curve during the experimental test. OA knees had a lower flexion angle than healthy knees. There is a difference of about 20° between the flexion-extension amplitude of the average cycle of healthy sample and of patients sample before TKR, and the difference in the amplitude is about 10° if the comparison is made with the prosthetic knee after 4 month from TKR surgery. This is explained by the reduction in the possibility of flexion caused by osteoarthritis, by the influence of the pain of the diseased knee and by the tendency of the body to maintain stability at the time of reaching a higher flexion angle.

4. Conclusions

This paper presents a study of influence of TKR surgery on an osteoarthritic knee on the kinematical parameters of the knee flexion-extension on a sample of patients suffering of osteoarthritic knee disease. The TKR surgery represents a solution for OA treatment, which improves the quality of knee movement by stabilizing the joints and increasing the range of motion of knee flexion-extension, reducing pain and the minimizing the knee joint stresses. The influence of the prosthetic device was positive on the movement rehabilitation. The experimental tests show that there is an improvement in knee movement after TKR surgery and alleviating the pain caused by the destruction of the knee cartilages. In addition, the peak amplitude value of OAK flexion-extension movement significantly increased, being closer to the amplitude of healthy knee.

5. References

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