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An inexpensive solution for tracking the knee flexion angle for patients in motor recovery
O soluţie ieftină de urmărire a unghiului de flexie a genunchiului pentru pacienţii aflaţi în recuperare motrică

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Abstract

Background. The knee flexion angle is an important parameter to follow for patients in motor recovery. By measuring this parameter frequently during walking, the physicians are able to reach some conclusions on the state of the patient, in terms of recovery of motor functions. Unfortunately, in low income countries, this is almost impossible because of the rarity or lack of the equipment and/or specialized rehabilitation centers where this procedure can be performed.

Aims. This paper mainly aims to demonstrate that knee flexion is recovered differently depending on the patient, and also proposes an inexpensive solution for the tracking of the knee flexion angle during the recovery period.

Methods. By using a motion capture and analysis system, we obtained a series of experimental data, specific for patients in motor recovery. Using these data, we were able to extract the knee flexion angle during three sessions over twenty days during postoperative recovery (the video recording sessions beginning 10 days after surgery). In our study we used data from three patients who had suffered a total knee arthroplasty surgery and were in postoperative motor recovery.

Results. After performing the motion capture and analysis procedures, it was found that the knee flexion angle values measured over three sessions during the twenty days were significantly different for the three patients.

Conclusions. After a total knee arthroplasty procedure, the patients recover their knee flexion angle differently. During the recovery period, having access to frequent data about the knee flexion angle (in walking) will help the therapist to adjust the recovery procedures specifically for each patient, for a more efficient recovery.

Keywords: motor recovery, motion analysis, biomechanics, knee flexion angle, total knee arthroplasty.

Rezumat

Premize. Unghiul de flexie al genunchiului este un parametru important în perioada de recuperare motrică a unui pacient. Prin măsurarea repetată a acestui parametru în timpul mersului, postoperator, odată cu începerea perioadei de recuperare, medicii au posibilitatea de a ajunge la o serie de concluzii asupra stadiului în care se găseşte pacientul, din punct de vedere al recuperării funcţiilor motrice. În ţările cu venituri mici, acest lucru este aproape imposibil, datorită rarităţii sau chiar lipsei aparaturii şi/sau centrelor de recuperare specializate unde s-ar putea realiza această operaţiune.

Obiective. Acest articol îşi propune să demonstreze în principal faptul că flexia genunchiului se recuperează în mod diferit în funcţie de pacient şi, în mod secundar, propune o soluţie ieftină pentru a realiza urmărirea unghiului de flexie a genunchiului de-a lungul perioadei de recuperare.

Metode. Cu ajutorul unui sistem de înregistrare şi analiză a mersului, am obţinut o serie de date experimentale specifice pentru pacienţii în recuperare motrică. Folosind aceste date, am extras valorile unghiului de flexie a genunchiului pacienţilor pe parcursul a trei sesiuni de-a lungul a douăzeci de zile de recuperare postoperatorie (înregistrările au început la 10 zile după intervenţia chirurgicală). În studiul nostru am folosit datele pentru trei pacienţi ce au suferit o operaţie de înlocuire totală a articulaţiei genunchiului şi se aflau în perioada de recuperare a funcţiilor motrice.

Rezultate. În urma înregistrărilor şi analizei mişcării, se constată că valorile unghiului de flexie a genunchiului, măsurate de-a lungul celor trei sesiuni pe perioada celor douăzeci de zile, sunt vizibil diferite pentru cei trei pacienţi.

Concluzii. Pacienţii îşi recuperează diferit unghiul de flexie a genunchiului în urma unei proceduri de înlocuire totală a respectivei articulaţii. Cunoaşterea frecventă a unghiului de flexie în mers a pacienţilor aflaţi în recuperare motrică va ajuta kinetoterapeutul în a adapta procedurile de recuperare în mod specific pentru fiecare pacient, pentru o recuperare cât mai eficientă.

Cuvinte cheie: recuperare motrică, analiza mişcării, biomecanică, unghi de flexie a genunchiului, artroplastie totală de genunchi.

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Introduction

After a total knee arthroplasty surgery, patients in motor recovery are instructed to follow a specialized recovery program which consists of specific recovery procedures and techniques, or at least to frequently perform some series of physical exercises (Cup et al., 2007; Daves et al., 2006; Hardling et al., 2005). These procedures should be prescribed based on an individualized approach which considers many factors that influence the recovery process. Unfortunately, in low income countries, the paraclinical tools that help create this individualized approach are usually very rare or do not even exist. This leads to high patient dissatisfaction after total knee arthroplasty (Nam et al., 2014). It is common sense that patients recover their motor functions differently, influenced by factors such as age, sex, medical history, mental attitude, etc. (Allen et al., 2014) and therefore, each patient should be targeted individually, using a specific recovery program (Minns et al., 2007; Simpson et al., 2014). In order to be able to develop customized programs for every patient, analysis of their gait would help considerably (Molloy et al., 2008). In developed countries, this might not be such an important issue, but in low and even some middle income countries, we have to talk about an effective coverage of medical services before we can even take customized recovery programs into consideration (Debas et al., 2006; Ozgediz et al., 2009). For example, according to local recovery and rehabilitation physicians, in Romania, only one out of three patients who undergo a total knee arthroplasty procedure (our data refer only to procedures supported by the country's national healthcare system, excluding private clinics) will follow a dedicated post-operative program. On the other hand, it is proven by the literature (Akça & Doğan, 2012) that exercising at home helps reduce symptoms associated with osteoarthritis. Therefore, an acceptable solution to create a customized recovery program for low income countries would consist of a simple, inexpensive, portable and easy to install and use motion analysis system to be used at home or in a nursing home.

Hypothesis

In this paper, we present the capture and analysis of the knee flexion angle, an important gait parameter in motor recovery following a total knee arthroplasty procedure. The data are collected and analyzed by using an inexpensive, portable, easy to install and use motion analysis system, designed to be used frequently, at home or in a nursing home. We believe that, by adapting to the rate of recovery for this parameter, which we prove is specific to each of the three considered patients, physicians would be able to design recovery exercise programs with higher degrees of customization, which will lead to an overall better motor recovery.

Material and methods

A motion analysis system can be divided in hardware components (components which are used for motion recording) and software components (components used for the digitization of motion data, followed by the analysis of digitized data). We designed the motion analysis system aiming to avoid the use of any hard-to-find components, so that it can be easily implemented in any part of the world.

The idea behind this system's components and installation conditions was to be able to easily install such a system at home. From the hardware perspective, a 60+ frames per second video camera is needed along with a good, solid tripod and long power cables. We obtained decent results using a 63 frames per second video camera - a more expensive, 500 frames per second camera is not required, but welcomed. The video materials in this paper were recorded at 63 frames per second.

From the software perspective, two things are needed: software able to track the motion, extract the motion data and export them in a digital form to some commonly used type of database, and a set of programs which can analyze the digital data, in order to offer results that have meaning for the physician. For this paper, we considered for analysis the knee flexion angle (Fig. 1).

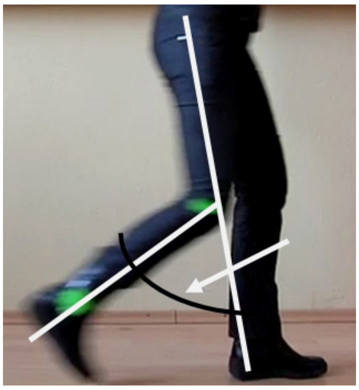

Fig. 1 – The knee angle which we captured and analyzed in this paper.

It was very important for us to choose software that is very popular, so there would be no regional limitations related to software. We have chosen Adobe After Effects (even if it is not specifically dedicated for human motion analysis, it is a very popular application, designed by a software giant, so it is likely to receive updates for a long period of time). For motion analysis, we chose Matlab (a great engineering application, it offers a lot of tools related to advanced analysis, with the use of curve fitting techniques, etc.), but it is not an exclusive requirement - any programming language which can read Excel files should be suited for the task.

The decisions above were also taken because we wanted to make sure that the system would actually have its use, considering low income countries: motion data can be recorded at the patient's home or in a nursing home.

Our subjects were all female, over 60 years old, suffering from gonarthrosis (arthrosis of the knee). They were treated with total knee arthroplasty (total replacement of the knee). They followed the normal, classical rehabilitation routine which implies different physiotherapy procedures and exercises during the recovery period. During 20 days (starting 10 days after surgery), we video recorded and analyzed the motion of their affected leg.

For each patient, we had a video capture session every 10 days, at the patient's home. All patients used a walking frame for support. They performed 10 walks in a normal gait during each session, covering a fixed distance of 2.3 meters for each walk. The camera was placed laterally, at 2.8 meters, perpendicular to the direction of walking and in the middle of the distance, so that it covered the sagittal plane of the subjects. Markers were installed on the ankle, knee and hip of the patient. The camera was placed at a height of 30 cm from the ground. The numbers were chosen based on our previous studies (Mihalcica et al., 2014; Munteanu, 2014), which delivered good results.

To better understand the procedure, we will describe how things work for a subject of the experiment:

- the system is set up as described above, markers are installed at the position of the joints (the subjects wear the same clothes, as fixed to the body as possible, with the markers fixed in the same spots during all sessions - practically, the patients use the same set of clothes without removing the markers).
- the subject starts walking (the first step is made with the affected leg) and, at the same moment, the camera starts filming
- the subject exits the frame, the camera stops filming
- the video material is saved to the computer
- the video material is then imported in VirtualDub where we cut the extra material, so that the subject walking from the starting point to the end point is all that remains
- the video material is then imported in Adobe After Effects, and then the tracking tool is used (Animation/Track Motion) on the three markers, one by one (Fig. 2).

Fig. 2 – Tracking the ankle motion in Adobe After Effects.

- the ankle, knee and hip markers are followed during the walk and the trajectory is then exported in Excel, as X-Y pairs of coordinates for each frame
- data are pre-processed using a program developed in Matlab (realigned to 0.0 as origin)
- data are processed using a second program developed in Matlab, to determine the trajectory of the ankle, knee and hip; this is graphically represented in time (Fig. 3).

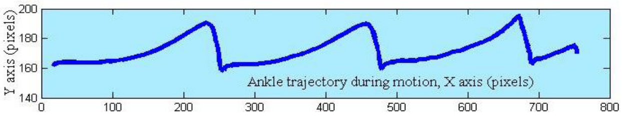

Fig. 3 – The ankle trajectory for a subject, processed with MATLAB.

- data are processed using a third program developed in Matlab to determine the flexion angle of the knee

We present the evolution of the knee flexion angle, during a walk (Fig. 4). We have the coordinates for the ankle, knee and hip, and from the triangle formed, this angle is easy to determine. This angle of flexion is then extracted for each step, and then an analysis is done in order to extract important information about the state of recovery of the patient. This information can lead to adaptations and modifications of the recovery program, which will help the patient in his motor recovery.

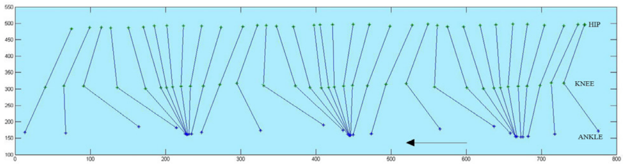

Fig. 4 – Model of the leg during walking, after the joint coordinates are obtained.

We recommend that the gait parameters should be calculated and analyzed in at least one session every two weeks, with an ideal of two sessions per week. More data not only lead to a better analysis, but also to a faster identification of serious progress or a possible issue. The idea is to observe the progress of recovery for the patient in time. At the discretion of the physical therapist, changes in the recovery program or changes in walking devices might be needed, as the long-lasting use of a walking device or the inappropriate selection of such a device has a negative impact on the patient (Poncumhak, 2014).

Results

For patients in recovery after total knee arthroplasty, the ideal situation is being able to bend the knee to at least 130 degrees (to obtain a knee flexion angle of at least 130 degrees), with 110 degrees being a minimum needed to perform regular activities (Devers et al., 2011). We are interested in the same knee flexion angle, but this time during normal walking. Obviously, the values are lower (the normal maximum knee flexion angle during a full stride for a healthy person is considered to be around 60 degrees). The analysis of this angle provides a lot of information about motor recovery - being able to flex the knee better during normal walking is a positive thing, especially considering the fact that a good recovery would imply that the patient is able to perform well during natural activities such as walking up and down the stairs, gardening, etc. The presented graphics contain the value of the knee flexion angle in degrees on the Y axis and the time, in frames, on the X axis. Considering a 63 frames per second conversion rate, the value of time in seconds can be easily calculated (we present the graphics in pixels only to show full values on the X axis, as time does not influence in any way the results in this analysis).

If we analyze the maximum knee flexion angle in walking for the first subject during the three sessions, we observe just a small improvement from the first session to the second, followed by a significant improvement from the second to the third session. The overall improvement for the maximum knee flexion angle was an important one, going from about 42 degrees to about 60 degrees (Fig. 5).

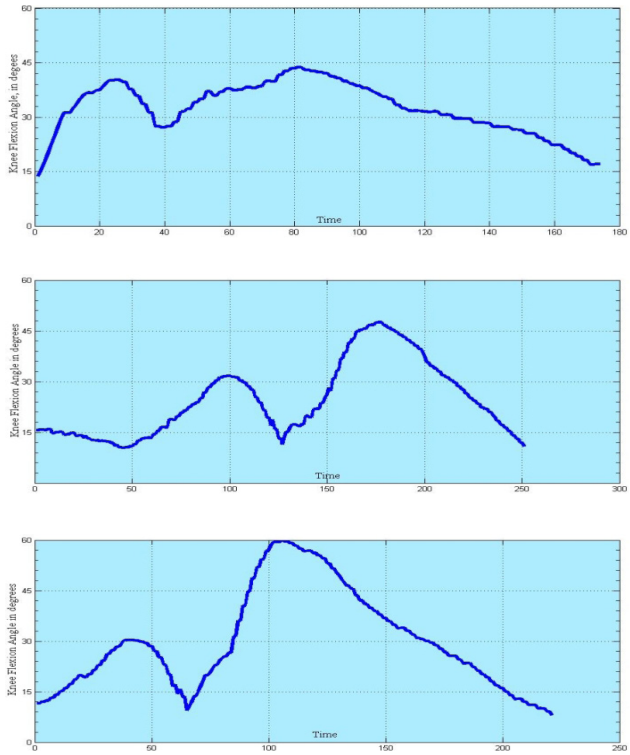

Fig. 5 – The knee flexion angle for a full stride, in degrees, during the three sessions, for the first subject.

For the second subject, it is easy to see that the overall improvement for the maximum knee flexion angle is significantly lower compared to the first subject (only about 6 degrees, from about 51 to about 56 degrees), with the major change occurring between the first two sessions and not between the last two, as in the case of the first subject (Fig. 6).

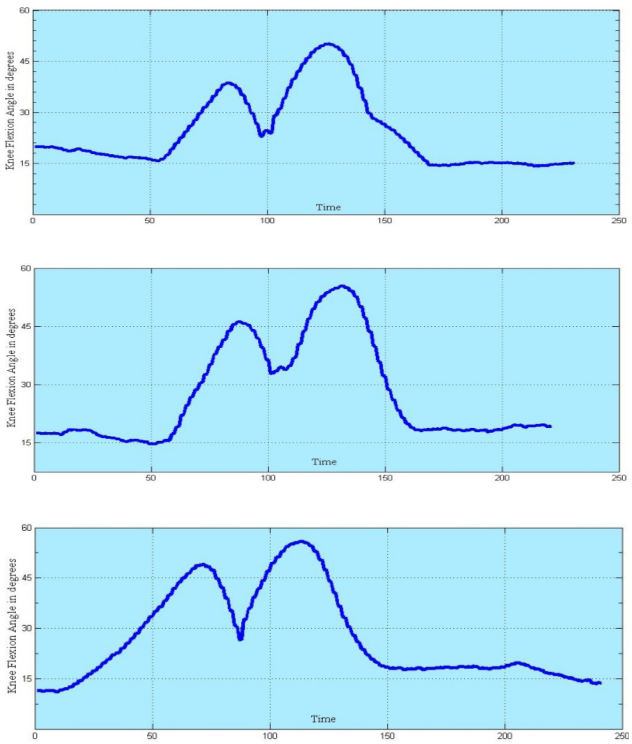

Fig. 6 – The knee flexion angle for a full stride, in degrees, during the three sessions, for the second subject.

For the third subject, we can observe a significant and steady improvement for the maximum knee flexion angle between all the sessions. The subject progresses from a knee flexion angle of about 40 degrees during the first session to about 49 degrees in the second session, and about 56 degrees during the third session (Fig. 7).

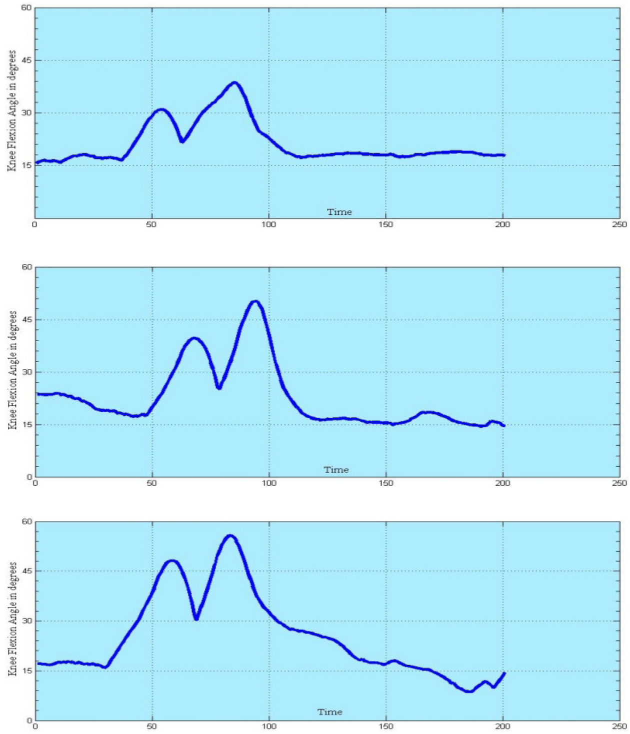

Fig. 7 - The knee flexion angle for a full stride, in degrees, during the three sessions, for the third subject.

These results show that each of the three subjects has their own patterns regarding the recovery of the knee angle, and this factor should be taken into consideration when designing a customized recovery exercise program.

Discussion

In order to track the knee flexion angle, we aimed to design a motion analysis method that is inexpensive, easy to install and can be used at the patient's home or in a nursing home, with the help of one or more family members/staff. This is not an easy task, because the system needs to be installed at the exact same position for each recording session (the camera distance, the walking distance, etc., all need to be the same). For a possible replication of the experiment, the patient and his helpers should be clearly instructed in this area.

For motion capture and analysis, we considered only one leg. We are sure that better results would be obtained by gathering data also for the other leg, but this would mean that the subject needs to be filmed from both sides - this is difficult to obtain, especially if the video recording sessions take place at the patient's home (space limitations). Other solutions were explored, such as using different radio technologies (GPS) but we wanted the system to be totally non-intrusive, widely available and not to influence the patient's walking patterns in any way (installing heavy sensors on the leg is usually not a good idea). Also, we decided to choose this "paper markers" approach because it is simple and safe for the patient - not using any electrical devices installed on the patient's body was important for us, as many patients in motor recovery are elderly people.

As future research, there are more interesting aspects to observe, one being the difference in the knee angle "shape" between sessions recorded with the patients using a walking frame and those recorded with them using a cane. If we look at the flexion angle of a patient when using the walking frame and compare it with the angle of the same patient when using a cane, we can see that the angle while using the walking frame has a specific, shorter and sharper shape and the angle while using the cane resembles somehow the shape that we see in healthy people, so the change from the walking frame to the cane has a serious impact on the patient's gait. However, this needs a specific analysis in order to be able to draw useful conclusions (Fig. 8).

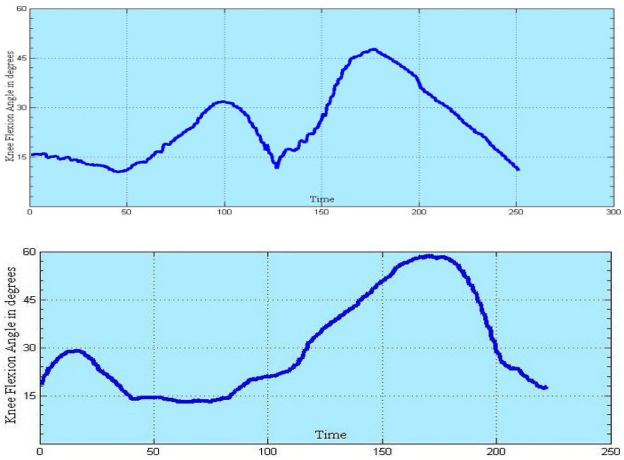

Fig. 8 – The knee flexion angle for a full stride, in degrees, for the same patient using a walking frame (left) and a cane (right).

Conclusions

1. We were able to determine the variation of the knee flexion angle for patients in motor recovery, over three sessions during their postoperative recovery program. Significant differences in the angle values between three patients were observed, and we can say that the patients recover their knee flexion angle differently. We believe that physicians who have access to these frequently recorded data are able to adjust and customize the recovery program for the patients.
2. Data capture and analysis procedures were performed by using an inexpensive, portable, easy to install and use motion analysis system, which might be a solution for motion analysis in low income countries.
3. As future research, we aim to establish a set of at least 5 relevant geometric and kinematic parameters for patients in motor recovery, which we can follow in time so that we can have a better picture of the recovery specifics of each patient. Also, analysis of gait for patients using different support (walking frame, cane and no support at all) is planned.

Conflicts of interests

There were no conflicts of interests.

Acknowledgement

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