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Tracking Kinematic Gait Parameters During the Recovery of Motor Function After Total Knee Arthroplasty

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Abstract

One of the important issues concerning physical medicine and rehabilitation, especially in underdeveloped countries, is tracking the progress of recovery for a patient by using more than clinical parameters. Unfortunately, in low income countries (but not only), for financial reasons, many patients do not even follow a recommended recovery and rehabilitation exercise program, and, from those who do, only a few benefit from specifically customized ones. In this paper we present a series of gait parameters which are important for the rehabilitation for patients in motor functions recovery. The data is collected and the gait parameters are obtained with the help of an inexpensive and portable motion analysis system, suitable for implementation in low income countries. By analyzing these parameters, we prove that, considering the gait perspective, three patients who have been treated using the same surgical procedure recover their motor abilities differently from each other. This proves the importance of a customized recovery program, which does not rely only on the clinical approach.

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Keywords: inverse kinematics; motion capture; gait analysis; physical medicine; rehabilitation and recovery.

1. Introduction

Health care in low income countries is an important issue, and the problems are the more visible as the medical procedures involved are more complicated. For example, the patients from our study were diagnosed with advanced

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gonarthrosis (arthrosis of the knee) for which the only efficient treatment in that stage would have been TKA (total knee replacement – the knee joint is completely removed surgically, being replaced with a prosthetic knee). At that moment, the decision for the patient was a purely financial one: choose a private clinic, where the cost of the surgical procedure was over ten times the average monthly pension in Romania, or wait for more than a year on the list for a procedure that is covered by the Romanian medical and insurance policies. It is important to note that all the patients whom we analyzed are retired women over 60 years old, and that the elderly are the main subjects for this kind of surgical procedure.

The things are very similar when it comes to recovery and rehabilitation – only a low percentage of patients (from those who follow the insurance covered procedure) follow a dedicated and efficient recovery program, despite the benefits [1]. To be fair, the patients receive both guidance and an physical exercise plan for the post-operative recovery, medical doctors do what they can but financial reasons stop many patients benefiting from a recovery and rehabilitation program which should be customized for every patient [3].

A lot of negative things add together: the improper coverage of medical services in low and middle income countries [2, 10], the growing dissatisfaction rate among patients regarding the TKA procedure [9] and the lack of a customized rehabilitation program. A change in this system should be marked as mandatory. Therefore, in order to work in a low income country, a recovery program should be not expensive while efficient and customized for each patient [11]. Also, it would tremendously help if the program can be followed at home or at a nursing home. Following this idea, we present in this paper an easy and low income countries suitable way to gather gait experimental data and four parameters to follow in order to help create a customized recovery program.

Considering the studies focusing on patient treatment at home, a large number of studies from which we cite just a few [16, 17] are interested mostly in the clinical aspect of rehabilitation and recovery (measuring and evaluating pain) while adding static aspects like the total time needed to walk a fixed distance, the knee flexion when sitting, the knee range of motion etc. The advantages of our research is that we can frequently determine a whole range of kinematic parameters for a patient during walking, using an inexpensive system and a simple method, while gathering the data at the patient's home.

2. Materials and methods

For the gathering and analysis of experimental data, we used a simple motion capture and analysis system composed of a video camera, digitalization software and analysis software – we used Adobe After Effects to transform data captured from video materials into digital trajectories, and programs written under MATLAB to analyze these trajectories [5].

As subjects for our study, we had three female patients which suffered a TKA procedure. All of them were over 60 years old and all of them followed the insurance-covered procedure. We analyzed their gait for 8 weeks during their postoperative recovery. For the purpose of this paper, we will focus on 3 early weeks of this period of time (the recordings started 10 days after the surgery), when all patients were using a walking frame for support during locomotion.

The procedure for data collection and analysis is graphically described in Fig. 1. Each subject was walking in front of the video camera, for a fixed distance (for this study it was 2.3 meters) in normal gait, assisted by a walking frame, during multiple sessions, multiple times during each session [8]. The subjects had markers installed on the most important leg joints (the ankle, the knee and the hip) and their gait was recorded during each walk [12, 14]. In the end, a series of video materials for each patient during each recording session were obtained. These video materials were then imported one by one in Adobe After Effects. Using the motion tracking tool specific to this application, three trajectories (one for each marker) were obtained for each video material. An example for the ankle marker is presented in Fig. 2. These trajectories consist of pairs of (X,Y) points in the plane of motion, saved as Excel tables [7].

Having the trajectories of each marker and knowing the time frame, we were able to determine many geometrical and kinematic parameters for each subject. For this paper, the parameters which we were mostly interested in were: the velocity of the subject during each session, the maximum height of the ankle during gait, the maximum height of the knee during gait (how far can the patient lift their ankle and knee) and the length of the stride (step) [4].

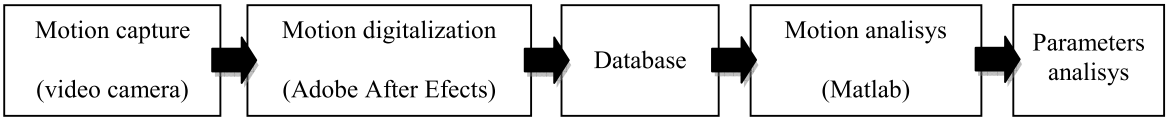

Fig. 1. The motion capture and analysis procedure.

As working with pure numbers might not be accurate, considering the different dimensions for the body segments of the subjects, we approached the parameters above as a percentage, looking for specifically how much improvement, in percents, was obtained during the different walking sessions [13]. For consistency, from all the sessions, we have chosen three for analysis: the first session was recorded during day 10 (postoperative), the second session took place in day 21 and the third in day 31 [6].

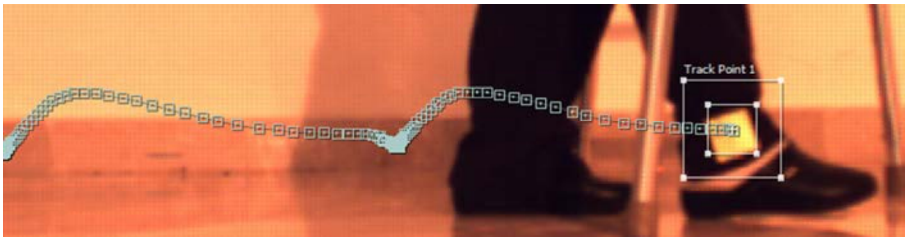

Fig. 2. The ankle marker's trajectory during a walking session, captured using the procedure described above.

3. Results

For each subject, we will present the values of the four parameters which we considered for analysis. Most distances are presented in pixels, as for this analysis we were mostly interested in their evolution in percents and not their absolute values.

Table 1. The parameters for the first subject.

	Session 1	Session 2	Session 3
Velocity (m/s)			
Distance (m)	2.30	2.30	2.30
Time (s)	12.36	7.87	5.69
Mean Velocity (m/s)	0.186009	0.292138	0.404218
Height of the ankle (pixels)			
First step	21.74	23.58	30.29
Second step	22.43	23.34	29.05
Third step	22.76	23.24	30.41
Average ankle height	22.31	23.39	29.92
Height of the knee (pixels)			
First step	7.67	10.11	11.49
Second step	7.23	9.49	11.35
Third step	7.55	9.76	11.16
Average knee height	7.48	9.79	11.33
Length of the stride (pixels)			

Stride 1	184.33	217.89	223.19
Stride 2	181.62	228.91	231.31
Average stride length	182.98	223.40	227.25

For the first subject, we can observe a significant improvement regarding the velocity of motion between the first and the second session, while the height of the ankle was significantly higher only between the second and the third session.

As another thing that stands out, we can also observe that the length of the stride has the tendency to become stable (presented in Table 1). The complete values regarding the improvement of the considered parameters for the first subject can be seen in Table 2.

Table 2. The improvement for the first subject, in percents, from session to session.

Improvement	Session1 to session 2 (%)	Session 2 to session 3 (%)	Total improvement (%)
Velocity	57.06	38.37	117.31
Ankle height	4.84	27.92	34.11
Stride length	22.09	1.72	24.19
Knee height	30.88	15.73	51.47

For the second subject, we observe a major fact – if in the first two sessions it took the patient more than 4 full steps to walk the distance, in the last session only 3 full steps were necessary. As parameters, we see the same major improvement between the first and the second session regarding velocity but also a serious improvement for the length of the stride and the height of the knee between the second and third session. The complete values of the parameters for the second subject can be seen in Table 3 and the improvement over time is presented in Table 4.

Table 3. The parameters for the second subject.

	Session 1	Session 2	Session 3
Velocity (m/s)			
Distance (m)	2.30	2.30	2.30
Time (s)	11.63	6.76	5.46
Mean Velocity (m/s)	0.197764	0.340237	0.421245
Height of the ankle (pixels)			
First step	18.51	19.46	23.49
Second step	19.12	20.23	23.95
Third step	18.92	20.11	23.14
Fourth step	19.23	19.92	X
Average ankle height	18.95	19.93	23.53
Height of the knee (pixels)			
First step	4.15	5.92	7.29
Second step	4.22	5.63	7.45
Third step	4.18	5.29	7.71
Fourth step	4.39	5.13	X
Average knee height	4.24	5.49	7.48
Length of the stride (pixels)			
Stride 1	156.69	181.40	228.37
Stride 2	158.83	175.21	219.55

Stride 3	159.75	178.36	X
Average stride length	157.46	178.31	223.96

Table 4. The improvement for the second subject, in percents, from session to session.

Improvement	Session1 to session 2 (%)	Session 2 to session 3 (%)	Total improvement (%)
Velocity	72.04	23.81	113.00
Ankle height	5.17	18.06	24.17
Stride length	13.24	25.60	42.23
Knee height	29.48	36.25	76.42

Regarding the third subject, we can observe in this case that it took more than 4 full steps to walk the distance. Also, the improvements regarding these motion parameters seem to be somehow steady but lower when compared with the other subjects. The complete values of the parameters for the third subject can be seen in Table 5 and the improvement over time is presented in Table 6.

Table 5. The parameters for the third subject.

	Session 1	Session 2	Session 3
Velocity (m/s)			
Distance (m)	2.30	2.30	2.30
Time (s)	8.21	6.46	5.76
Mean Velocity (m/s)	0.280146	0.356037	0.399306
Height of the ankle (pixels)			
First step	11.27	12.23	15.49
Second step	11.48	12.29	15.88
Third step	11.23	12.84	15.17
Fourth step	11.59	12.57	15.33
Average ankle height	11.39	12.48	15.58
Height of the knee (pixels)			
First step	5.07	5.50	6.05
Second step	5.27	5.88	6.25
Third step	5.29	5.92	6.11
Fourth step	5.17	5.79	5.98
Average knee height	5.20	5.77	6.10
Length of the stride (pixels)			
Stride 1	141.53	149.15	172.03
Stride 2	148.45	158.43	164.73
Stride 3	142.75	154.16	169.39
Average stride length	144.99	153.79	168.72

Table 6. The improvement for the third subject, in percents, from session to session

Improvement	Session1 to session 2 (%)	Session 2 to session 3 (%)	Total improvement (%)
Velocity	27.09	12.15	42.53
Ankle height	9.57	24.84	36.79
Stride length	6.07	9.71	16.37

Knee height	10.96	5.72	17.31

4. Conclusions and discussion

As it can be seen from the considered parameters, the efficiency and time of recovery for the four considered parameters is different between the three patients. These differences tell us that the recovery has a different “shape” for each subject. For example, a patient might have a significantly higher velocity after three weeks, compared with the first day of recovery, which is a good thing, but on the other hand, the same patient might show only minimal improvements regarding the height to where he/she can lift the knee or ankle. While a high velocity might be a positive thing for walking on a perfectly plane surface, things might be problematic when we consider routine activities such as climbing stairs. In this situation, a change in the recovery program might be recommended.

While most studies in the field use the pattern "train using this set of exercises for one month or more, measure results", our study proposes frequent gathering and analysis of data. We profit from the fact that all our gait parameters are extracted from just the walking of patients, without stressing them to force-flex the knee or speed walk etc.

A pure clinical analysis, regarding pain, alignment of the leg, differences between the left and the right stride, is very important indeed. However, after seeing the significant differences between the parameters considered in this paper, which all affect gait and, in fact, directly affect the quality of life for patients, we claim that the pure clinical approach should be combined with some form of paraclinical analysis of gait in order to be able to design the right recovery / rehabilitation program, customized for each patient.

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