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Test exercise for a long-term monitoring of unilateral leg amputees in gonarthrosis therapy

https://doi.org/10.1515/cdbme-2024-2155

Abstract: Unilateral leg amputees suffer from an increased risk of gonarthrosis. The risk of substantial joint damage ca be decreased by an early diagnosis, therapy and long-term monitoring to regularly assess the knee joint's condition. To adapt the acoustic-kinetic analysis to unilateral amputees, a hand rig with Hottinger Quantum X440B and 2SM® sensors was added to the measurement setup. It helps the probands to keep their balance and to achieve a fluent motion during their test exercise of 3 knee bends in 10 seconds. The measurement setup comprises a Zebris® system to measure the vertical ground force, two Zebris Sync® Cams to assess the sagittal knee angle, the frontal horizontal knee shift and - in case of the amputees- the data of the hand forces via the Hottinger sensors. It is crucial to establish if the test exercise is adequate for the amputees and if the probands can perform the exercise regularly and over a long period of time with less than 10% - 20% variation. To this end a case study out of a pilot study of 18 case conditions and 108 measurements is presented to clarify the approach. The proband is female, 43 years old, with a unilateral amputation at the thigh. She does not suffer from arthrosis. She performed the test routine six times over a period of five weeks. The kinetic analysis resulted in a characteristic pattern, comparable to non-amputated patients. The results showed a good recurrence and therefore indicate that the test exercise of 3 knee bends in 10 seconds with hand support will be the exercise prospective studies.

Keywords: Long-term monitoring, unilateral amputee, standard exercise, gonarthrosis, acoustic-kinetic analysis.

1 Introduction

Unilateral leg amputees suffer from an increased risk of gonarthrosis [1, 2]. The risk of substantial joint damage can be decreased by an early diagnosis, therapy and long-term monitoring to regularly assess the knee joint's condition. The established acoustic-kinetic analysis measures pre-emptively damage to the cartilage of the knee's surfaces [3, 4]. A stable and reliable test exercise is crucial to the kinetic analysis, so a pilot study with 18 different conditions and 108 test measurements was initiated to establish a measurement routine that is adequate for patients with unilateral leg amputations and a test exercise that allows a long-term performance with a maximum of 10%-20% deviation, as required in biomechanical experiments. The probands performed a series of 3 knee bends within 10 seconds with hand support on a test rig equipped with sensors to assess the hand forces [5]. The proband was asked to perform the bend as deep as possible. As some deviation is to be expected in a long-term monitoring the analysis aims at patterns in the signal curves that relate to the biomechanical properties of phases of the knee bends, i.e. the acceleration and deceleration of the center of the body mass. To clarify the approach, one case study out of the pilot study is presented. As the proband does not suffer of gonarthrosis, it is expected that the pattern of the ground reaction force is similar to non-amputee's without arthrosis [6].

2 Method

To meet the requirements of the probands with unilateral leg amputations a test rig with handles including force sensors for the support to maintain the stability of the patient during the exercise was added to the original measurement setup [5]. The hand forces were included in the measurement parameters. The test setup for the acoustic-kinetic analysis therefore comprises the follwing components:

1. Zebris® System with FDM-S force plate to measure the ground reaction force,
2. two Zebris® SyncCam video cameras (1920x1080, 30fps) to document the movement,
3. Hottinger System Quantum X440B with two S2M® sensors (10N-1kN, class 2) to measure the hand forces.

The proband is a female, 43 years old, with a body weight of 78 kg and a body height of 163 cm. She is amputated on the right leg at the thigh and uses a Össur Rheo Knee with a carbon foot for normal gait. The daily mobility and the fitness is

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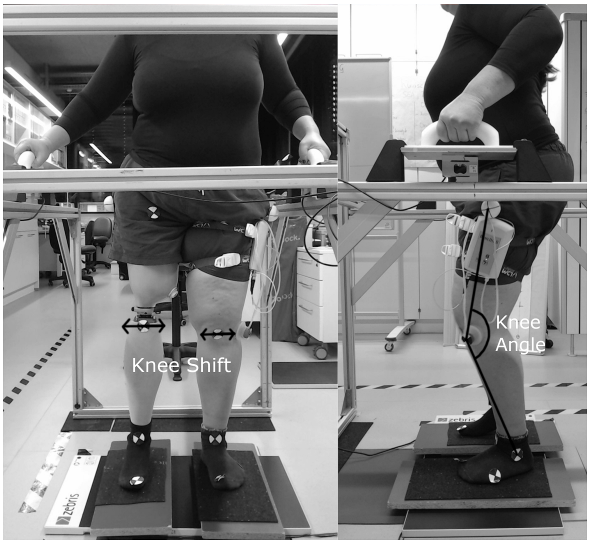

Fig. 1: Proband frontal and sagittal view. Horizontal translation as knee shift; sagittal knee angle; handles with force sensors; force plate with 3° inclination levels.

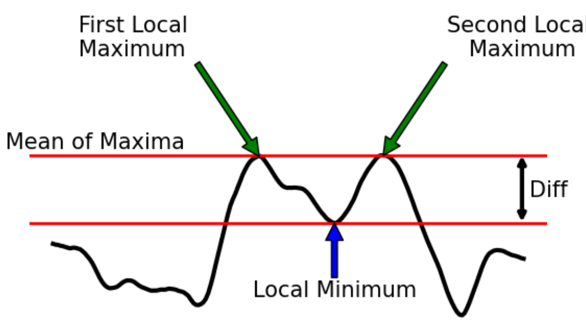

Fig. 2: Difference between average of local maxima (upper red line) and local minimum (lower red line) of the ground reaction force of a knee bend.

good because she exercises regularly Pilates. Due to the muscular imbalance the proband needs to support herself on the test rig while performing the knee bends. The hand forces are measured by the Hottinger sensors at the handles which are mounted on the test rig‘s sides at a height of 118 cm (frontal distance 81 cm). To analyse the support of the intact leg and the prosthesis leg during the three knee bends the ground reaction forces are measured by means of the Zebris® force plate. In addition, two Zebris® SyncCams (frontal and sagittal view) provide a video documentation of the knee bends. By means of the Tracker® software a set of markers on the patient‘s legs provides information on joint angles and the horizontal displacement of the knees (Fig. 1). The different data sets (ground reaction forces, hand forces, video) have to be synchronized with the help of trigger patterns of the maximal flexion and the upright stand of the three knee bends [6]. For the assessment of the test exercise the maximal values of the kinematical data and the hand force data of the knee bends are averaged while the difference between the minimum and the averaged maximum of the double hump pattern of the ground reaction is calculated (Fig. 2). In this paper the resulting forces and kinematic will be discussed with a prosthesis and a 3° inclination of the patient‘s feet.

3 Result and Discussion

3.1 Principles of the Pilot Study

The study was held over a period of 5 weeks. The proband took part in 6 sessions of experimental exercise and measurements with a one week interval. The first session served to verify that the test exercise of three knee bends within ten seconds were adequate for the proband under the planned conditions. She performed the bends with and without the prosthesis leg as well as with and without using the handles of the supporting rig. We aimed for a fluent movement without interruption within the time frame. To achieve this the proband suggested to switch off the steering of the prosthesis and to use the passive functions of the knee joint. Thus prepared the proper measurement series of 5 sessions at interval of 7 days started a week later [7].

3.2 Kinematics

The aim of this procedure is to ascertain if the exercise of the proband over the course of 5 weeks is repetitive with less than 10%-20% variation as required in biomechanical experiments. The relevant parameters for the kinematic assessment are the sagittal knee angle and the frontal horizontal translation of both knees. The knee bend is a stand-to-stand maneuver that can be described by the following phases: stance (starting point), flexion, turning point, extension, stance (end/starting point). The phases can be described by the sagittal knee angles with a maximum at the stance and a minimum at the turning point. (dotted lines in Fig. 3, Fig. 4 and Fig. 5). The horizontal shift of the knee joints is a sensitive parameter to describe the probands handling of the prosthetic knee in comparison to the contralateral knee. The distance is measured from the starting point of the first bend (0 Point) in centimeters. (Fig. 3 right leg=prosthesis). The proband tends to shift both knees slightly to her left side. She keeps her knees approximately in parallel in almost all test sessions. This indicates that she has sufficient control over the prosthesis to reproduce the test exercise in good quality over a period of several weeks (Tab. 1).

Tab. 1: Average (AVG) and standard deviation (STD) of translation maxima per day, distances relative to starting point of the curves.

Translation d/cm	Day 1	Day 2	Day 3	Day 4	Day 5	Average
Left Leg AVG	3.1	3.0	2.5	2.1	2.6	2.7
Left Leg STD	±0.1	±0.7	±0.2	±0.3	±0.2	±0.4
Right Leg AVG	0.6	1.0	3.71	2.3	3.72	2.3
Right Leg STD	±2.3	±0.3	±1.1	±0.7	±1.2	±1.3

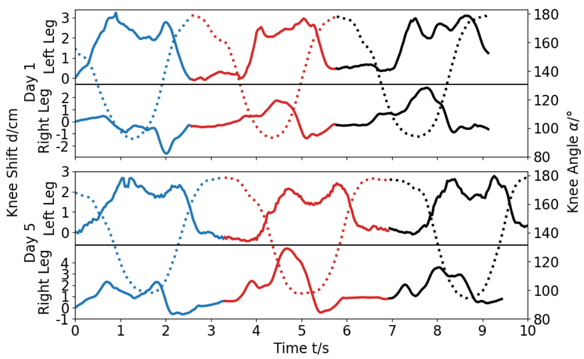

Fig. 3: Horizontal translation of the left and right knee; distance relative to the starting point of the first knee bend; sagittal Knee angle dotted; blue, red, black indicating each knee bend.

3.3 Ground Reaction Force

The three consecutive knee bends translate into a characteristic double humped curve pattern. A recurrence of the ground force pattern can be observed in all probands, with or without gonarthrosis and amputees and non-amputees alike. In Figure 4 the stance phase (dotted line = sagittal knee angle) the ground reaction force is at a minimum, then, at the beginning of the flexion there is a decrease of the ground reaction force, until the proband starts to decelerate the downward movement and the force raises to the first maximum. At the lowest and turning point the proband pauses what causes a local minimum in the ground force curve. At the turning point, the proband accelerates for the extension and produces the second maximum of the curve until the force of inertia supports the upward movement. The proband then reduces her acceleration and the ground reaction force reaches the next minimum. After this the proband prepares the stance and activates muscles to initiate the upright stance, causing a local maximum in the ground reaction force curve. The stance phase statistically is a plateau where the center is calculated by means of the neighboring minimums. The proband produced this characteristic pattern in the third knee bend of the first session. From the third session onward, all measurements produced the double hump pattern. The difference between minimum and the mean maxima of the double hump pattern converges (Tab. 2). The data of the third session must be interpreted as a spike due to emotional distress of the proband.

Tab. 2: Difference and standard deviation (STD) of local maxima and minima in double hump pattern.

	Day 1	Day 2	Day 3	Day 4	Day 5	Average
Difference F/%	1	3	7	5	5	4
STD F/%	±3	±3	±1	±2	±1	±2

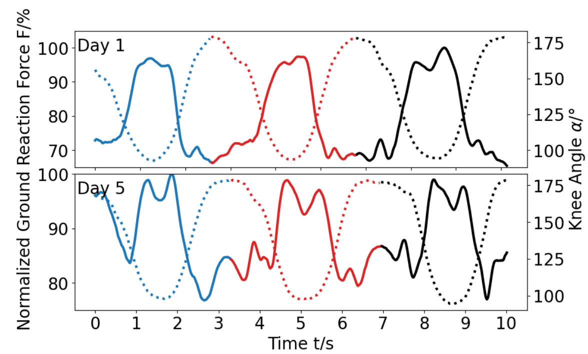

Fig. 4: Ground reaction force normalized with max values of the curves and sagittal knee angle (dotted) of Day 1 and Day 5 ; blue, red, black indicating each knee bend.

3.4 Hand Forces

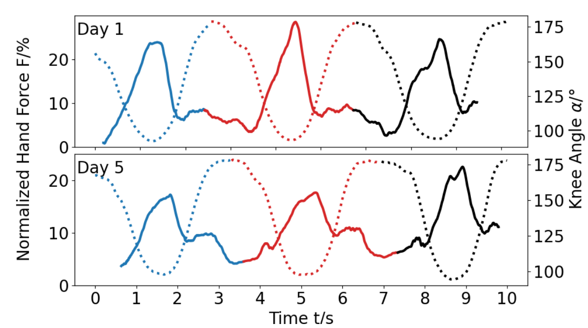

Fig. 5: Hand force normalized to maximum of ground reaction force and sagittal knee angle (dotted) of day 1 and day 5; blue, red, black indicating each knee bend.

To assess the contribution of the hand forces the amount of the total hand force is normalized by means of the body weight. In all curves of the total hand force two characteristics appear (Figure 5). First a maximum amplitude around the turning point of the minimum of the sagittal knee angle. And a second sub-minimum amplitude following the main max amplitude. It appears in the last part of the rise of the sagittal knee angle. These two characteristics are observed in every knee bend in all sessions. Hence the proband regularly has recourse to the support of the hand forces in the change from flexion to extension and the in the preparation of the upright stance. The

Tab. 3: Average (AVG) and standard deviation (STD) of maximum handforce per day.

Difference	Day 1	Day 2	Day 3	Day 4	Day 5	Average
AVG F/%	25.7	13.6	19.4	21.2	19.1	19.8
STD F/%	±2.2	±1.7	±2.9	±1.3	±1	±3.9

proband is working with her hands at almost all sessions in the same manner (Tab. 3).

4 Conclusion

The pilot study provided sample data concerning the measurement setup and the test exercise for the long-monitoring of unilateral leg amputees by means of acoustic-kinetic analysis. From the second session onward the proband generated the characteristic double humped curve of the ground reaction force and matching data sets in the kinetic analysis. The hand forces play a minor role in comparison to the ground reaction forces as their values are only in the range of 20% of the body weight. Nevertheless, the hand forces regularly support the knee bends around the turning point from flexion to extension. The test rig and handles support the fluency of the exercise and will be of use with elderly or less physically able patients. The measurement setup as well as the test exercise of “3 knee bends with hand support” is confirmed and will be the exercise prospective studies.

Author Statement

Research funding: The authors state no funding involved. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors’ institutional review board or equivalent committee.

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