GAIT ANALYSIS OF SUBJECTS WITH ANTERIOR CRUCIATE LIGAMENT RUPTURE USING MEDILOGIC® SOLE PRESSURE DISTRIBUTION MEASUREMENT SYSTEM

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1 Abstract

Nowadays gait analysis are very common in medical and athletic fields to determinate weakness of the basic human movement - walking.

The aim of this particular gait analysis was to verify the estimated changes of walking postoperative after injuries of anterior cruciate ligament.
Estimated were weight distribution to the forefoot and a difference of the duration of heel contact time. Further a dislocation of the centre of pressure to the not injured side was remarkable. This dislocation went from balanced to the not injured side.

For the analysis two subjects were analysed. First six weeks postoperative young men with anterior cruciate ligament rupture and second a control subject with no issues on his legs. Both were same size, weight and age for better comparison.

For the whole measurement MediLogic© sole pressure distribution measurement system was used.

2 Introduction

Injuries of anterior cruciate ligaments (ACL) are among the most common heavy sport injuries of lower extremities nowadays. Around 40 percent of all relevant knee injuries are occupied by cruciate ligament diseases. Statistically the anterior cruciate ligament is affected 10 times more often than the posterior one. Due to modern trends of fitness and health obsessions and thus often exaggerated examinations of sport activities the number of ACL injuries has dramatically increased during the last few years. Main responsibilities for risks of injury remain with stop and go sports like football or handball and alpine sports.

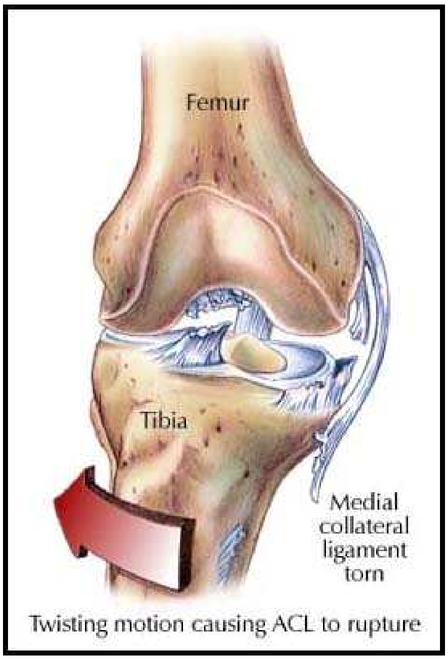

Fig. 1: Schematic drawing of the front view of a human knee joint (right) in nearly stretched position with ruptured ACL (http://www.hughston.com/hha/a_11_3_2.htm; 23.01.2012)

In case of a rupture of the ACL (ref. to Fig. 1), regardless of whether the ligament has been repaired by arthroscopy or non-operative treatments were applied, the gait analysis (GA) plays an important role in the visualization of the subject's recovery process. Regarding ACL patients, it is possible to detect the impacts of the injury on a subject's gait behavior via the GA and therefore make statements about the extent of the damage.

"The findings in this study indicate that when the anterior cruciate ligament is deficient, even the low-stress activity of walking on a level surface may be performed in an abnormal manner. This abnormal function could have long-term implications related to the changes that sometimes develop in knees in which a ruptured anterior cruciate ligament was never repaired or reconstructed." (Wexler, Hurwitz, Bush-Joseph, Andriacchi, & Bach, 1998)

GA can be done on various ways. One of the most commonly used methods in the past related to ACL-insufficiency was the video analysis. Combined with EMG (electromyographical)- and joint-torque measurements these investigations concentrated primarily on kinetic and kinematic parameters or muscle activities during gait. As a result of those studies a reduced stretch-torque of the knee joint combined with an increased stretch-torque of the hip joint (on the affected side) were determined on the majority of ACL patients. The subjects adapted their gait in a way of avoiding knee extension (reduced quadriceps activity) and increasing hamstring activity as to compensate reduced stability (of the artificial or missing ACL). Andriacchi called this effect the "quadriceps avoidance pattern" (Andriacchi & Birac, 1993). Furthermore a shorter heel contact period (initial contact, loading response) and a decreased heel pressure load were observed by Mittelmeier (Mittelmeier, et al., 1999).

Pressure based measurement systems like force plates or force sensors are another way to cope with the task of GA. These systems capture the direct impact of adapted motion during gait caused by ACL diseases, namely the sole pressure distribution. The ground reaction force progression of a regular human gait is characterized by a function providing two peaks, shaped like a camelback (ref. to Fig. 2). The first peak results from the body weight transfer (loading response). Afterwards the body's centre of mass accelerates downwards in direction of the ground. The second peak is produced by the push-off phase when heel is lifted and the body's centre of mass is accelerated in cranial direction (push-off phase).

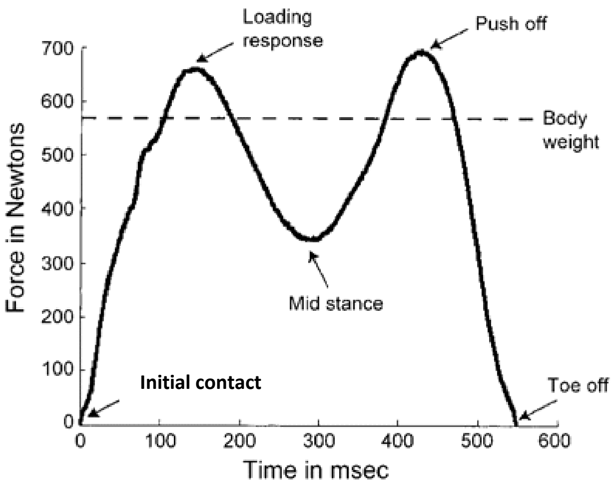

Fig. 2: Typical vertical ground reaction force pattern of a human gait cycle (http://cid.oxfordjournals.org/content/39/Supplement_2/S87.full; 22.01.2012)

The sole pressure progression is of similar shape (camelback) but with differences in the magnitude of the peaks. These differences can be explained by considering the distribution of occurring force amount over involved palmar contact surface, which varies during the progression of a foot rolling process (ref. to Fig. 3).

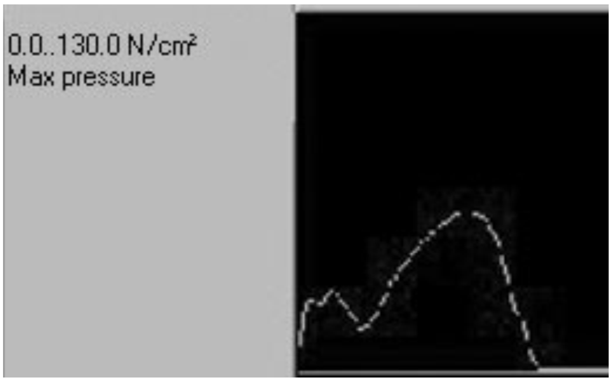

Fig. 3: Typical palmar pressure progress during human gait cycle (Rebel et al.)

Rebel et al. confirmed the "quadriceps avoidance pattern" in his studies using force plates.

Aim of this investigation was answering the question, whether the mentioned pattern can also be observed in walking tests using an insole force sensor system based on FSR technique like MediLogic© (T&T medilogic Medizintechnik GmbH, Schönefeld, Germany). According to the results of Rebel et al. it was expected to reveal clear signs (shortened duration of heel contact, increased forefoot weight distribution ratio, adapted palmar pressure histories) to verify the idea of the "quadriceps avoidance pattern".

3 Methods

Two male students participated in this investigation. S1 represented the ACL-insufficient subject (6 weeks postoperative, left side affected, age 24 years, 192cm height, 89kg weight) and S2 (physically healthy, no lower extremity disorders, age 21 years, 191cm height, 87kg weight) acted as control subject.

The gait analysis was performed by using the insole pressure measurement system MediLogic©. The MediLogic system, consisting of two insoles (in various standardized sizes) for left and right, a transmitter and a receiver plus evaluation software provides in-shoe measurement of pressure distribution over a wireless data transfer interface (ref. to Fig. 3).

Fig. 4: Basic parts included in the MediLogic-system (source: MediLogic manual Feb. 2008)

The system, in this case, operates with communication frequency UPAT4 (at 2,4Ghz). Depending on the size of insoles, each insole is equipped with up to 240 integrated force sensors, which are distributed in matrix pattern over the whole insole surface. In advantage to common FSR-sensors the MediLogic sensors are value calibrated and thus provide a quantitative evaluation of pressure values. Each single sensor has a measurement range from 0.6 to 64 N/cm². Insole sizes 45-46 (S1) and 43-44 (S2) were chosen by the subjects. For dynamic procedures like gait analyses it was recommended to use the maximum sample rate of 300 Mhz. Due to the absence of the original transmitter antenna datalogging-mode of the transmitter was enabled to avoid signal transfer losses. Data was recovered (after uploading from transmitter to PC) by the MediLogic-Software (V5.0). The software has been used for data recovery and export (to csv-files) only. All further procedures and evaluations were processed in MatLab (V7.11.0 (R2010b), The Mathworks Inc., Natick, MA, USA).

To prevent reliable data from distortion of measured values caused by wrong zero-load values (boot lacing, etc.) a calibration measure with subject in sitting position and dangling legs was captured. These calibration values were taken into account for each following measurement (measurement values reduced by configuration values). The Subjects were asked to perform a series of five walks on a plain obstructionless walkway at a normal moderate walking speed. The subjects started walking when datalogger was activated. In the following they had a time frame of four seconds to reach their usual walking cadence. The measurement itself lasted 20 seconds with an additional cooling down phase of another four seconds. The system indicated the beginning of each phase (run-in, measuring, cool-down) with a single significant beep tone as well as its running status with short-interval beeps. After each walk subjects rested for some seconds of recovery time before they started their next run.

For evaluation the single force sensors of each insole were drawn together into clusters according to anatomic palmar regions. The four main regions considered essential for this investigation were the areas of heel (H), big toe (T) and medial (BM) and lateral balls (BL). The sensor cluster configuration is shown in fig. 5. This resulted in ten series (left and right) of data per subject, where each series consisted of four clusters containing several striding cycles captured in samples (20x300 samples per run).

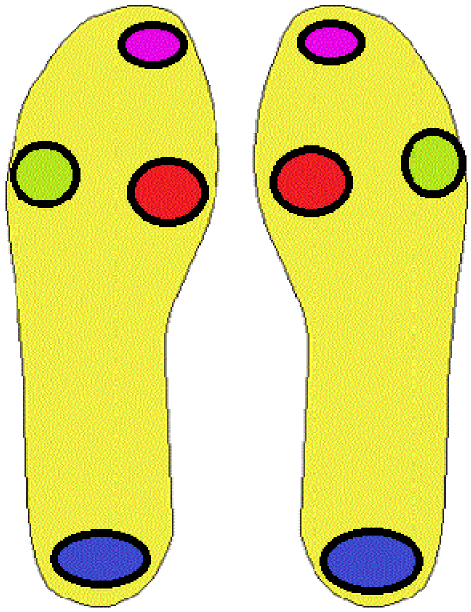

Fig. 5: Schematic sensor cluster configurations on the insoles – blue H, purple T, red BM, green BL

Due to the circumstance of a sensitivity problem of the right sole of subject S1 (sz. 45-46) the original intention of comparing real quantitative values had to be modified to a comparison of maximum-related (percentage of max. occuring value) values. For each cluster (H, T, BM, BL) the maximum occurring pressure value over all sensors and striding cycles captured during one walk was determined. To obtain one representative value per cluster, the mean value out of all sensors of a cluster was calculated. This value was refreshed every sample and put in relation to the determined maximum value. By chopping each walk into striding cycles and eliminating phases without ground contact of all palmar regions a sequence of various single foot contact phases (from IC to TO) were gathered. These sequences were used for the evaluation of statistical parameters for single foot contact phases.

The ground contact durations of the heel were evaluated by sample counting depending on the exceeding of a certain fixed value (6% of maximum heel pressure value) by the current (sample dependent) pressure value of the heel. This kind of evaluation provided a sensitivity of +/- 3.3ms.

Finally the evaluated data (heel contact duration, mean pressure progress of H, BM, BL and T, sole/ forefoot distribution ratio) of both subjects (and each side) were compared to each other for further conclusions.

4 Results

For analyzing of the gait of both subjects a mean single step model, left and right, was considered. In this analysis each sensor cluster was mentioned individual during the step. Further a mean pressure characteristic of all clusters, for a singles step (left and right) was analyzed.

S1 had a 30% higher pressure on his T and BM right side compared to left side (ref. to Fig. 6). Pressure on H was stable and on BL left side 20% higher. Also a noticeable is a 15% longer time period were pressure was on H. (ref. to Fig. 7)

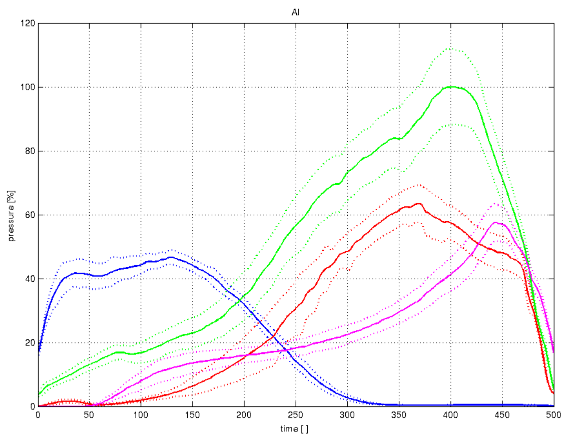

Fig 6: Pressure charatarisics S1 left side, blue H, purple T, red BM, green BL

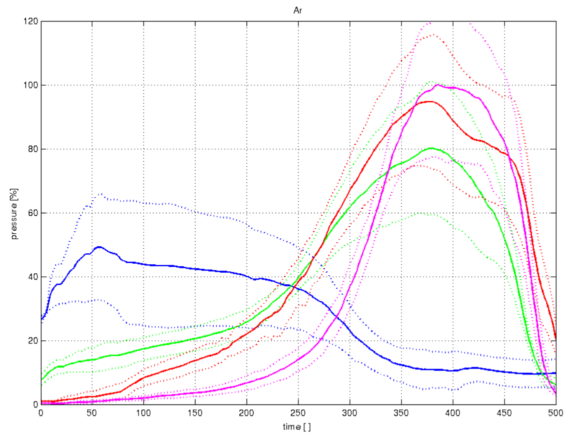

Fig 7: Pressure charatarisics S1 right side, blue H, purple T, red BM, green BL

In comparison S2 had very similar pattern, compared left and right, of his pressure characteristics. The only difference was 35% less pressure on H right side. (ref. to Fig. 7 and Fig. 8)

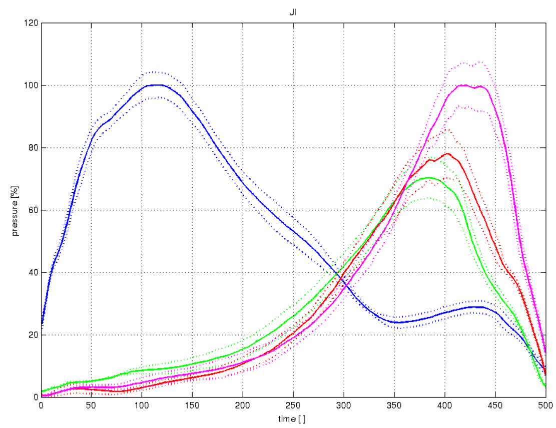

Fig 7: Pressure charatarisics S2 left side, blue H, purple T, red BM, green BL

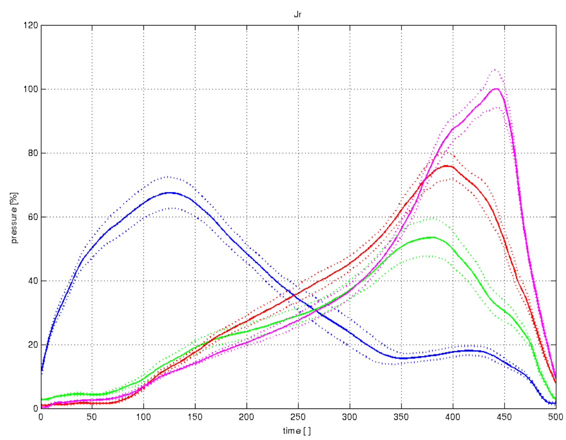

Fig 8: Pressure charatarisics S2 right side, blue H, purple T, red BM, green BL

The left and right mean pressure comparison of each individual showed a significant difference. The pattern of S2s graph was left and right very stable. (ref. to Fig. 9 and Fig. 10)

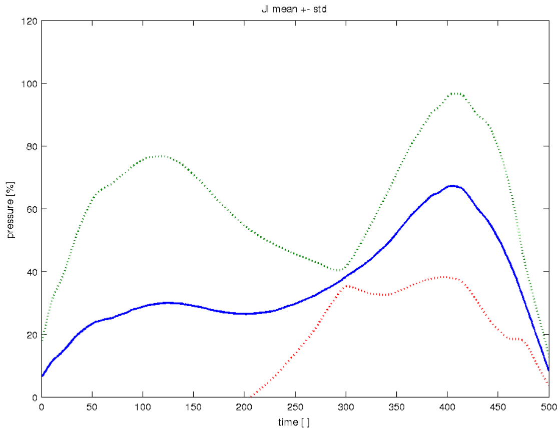

Fig 9: Mean pressure charatarisics S2 left side

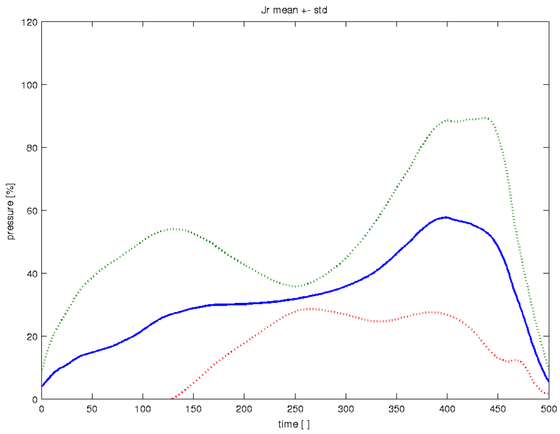

Fig 10: Mean pressure charatarisics S2 right side

S1 had a 40% higher average mean pressure right side. (ref. to Fig. 11 and Fig. 12)

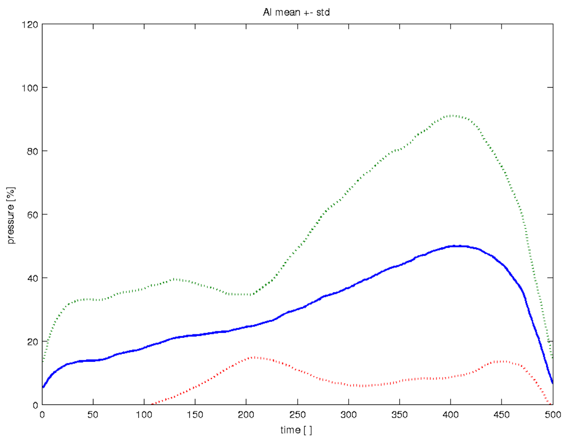

Fig 11: Mean pressure charatarisics S1 left side

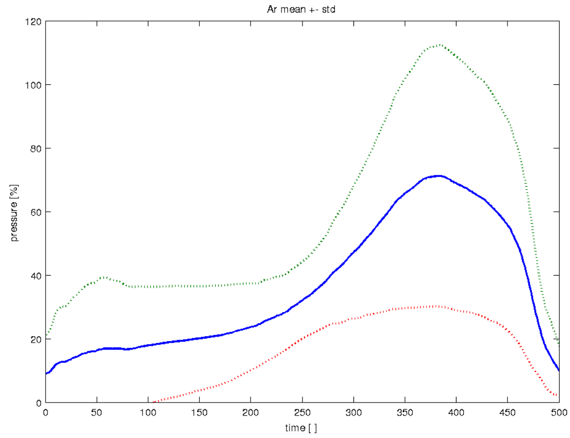

Fig 12: Mean pressure charatarisics S1 right side

5 Discussion

The answer of the question if the mentioned pattern from the introduction could be verified with FSR technique is not clear. A camelback shape of the mean pressure is noticeable on both sides. But the pressure of is in every case significant higher during push off in the forefoot than during loading response. A reason for that could be that S1 and S1 had relatively stiff outer soles on their shoes. That could make a huge difference compared to barefoot. However it is not possible to make a gait analysis with the used sensor because an insole has to be placed in a shoe. A control analysis with very flexible shoes with a thin outer sole could verify this hypothesis.

A shorted duration of heel contact was remarkable on S1s injured foot (left). Further the weight distribution ratio showed on S1 a clear drift to the right (not injured leg). That means the center of pressure went remarkably off the injured leg to rest the injured leg. In comparison the control subject S2 had his center of pressure always centered.

6 References

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