Joerg Subke*, Adeline Keller, Hermawan Hermawan, Michael Schmeiler, Benedict Schneider and Hans-Joachim Schwalbe

# Acoustic Emission Analysis (AEA) in unilateral leg amputees as a future quality tool in orthopaedic technology to evaluate the adjusted prosthesis in relation to gonarthritis

https://doi.org/10.1515/cdbme-2023-1179

**Abstract:** In orthopaedic technology unilateral leg amputees are provided with prosthesis which are attached through a shaft to the remaining part of the leg. The prosthesis legs are built according to manufacturer's specifications and get adjusted to the individual needs through motion analysis. If the prosthesis is not adjusted correctly to the individual needs of the user, the chance for development of arthritis in the remaining knee joint is greatly increased. The goal of this paper is to develop a procedure based on AEA to detect signs of arthritis in the remaining knee joint early and the base of a procedure for a future assessment of the quality of the care. The measurement system consists of the AEA – measurement device, a force plate to measure ground reaction forces, two strain gauges which are attached to handles on a test rig and two video cameras which record the movement from frontal and sagittal view. The amputee performs a standard movement in the test rig which consists of three knee bends in ten seconds while wearing the prosthesis legs. The test rig is provided so the amputee can support themselves using arms and hands as prosthesis' support during the extension phase of the knee bend. The posture and load of the knee joint during the movement is analyzed with the video and force data. The ground reaction forces show the load distribution between the remaining leg and the prosthesis and its support during the movement. The hand forces give clues how well the amputee can balance and which arm is favored under load. By combining kinematic data and AEA the state of the load transfer zones can be evaluated. Thus, it's possible to examine the remaining knee joint for defects and evaluate the quality of the prosthesis adjustment.

**Keywords:** Acoustic emission analysis, monitoring, unilateral leg amputee, adjusted prosthesis, gonarthritis.

## 1 Introduction

In the case of unilateral leg amputation, the patient is supplied with a modular leg prosthesis. Depending on the mobility of the patient the orthopaedic technician selects an adequate foot and knee prosthesis, sometimes of different manufacturers. According to the guidelines of the manufacturers the technician assembles the leg prosthesis and adapts it to the patient [1]. The quality of the assembly is proven by means of gait analysis and oral feedback of the patient.

If the assembly is not exactly suitable for the patient higher loads will appear on the preserved leg especially in the knee joint during the movement. In the worst case gonarthritis will occur within one year [2].

For the diagnosis of the development of a gonarthritis the acoustic emission analysis AEA provides the potential to detect lesions of the knee of the preserved leg in an early stage. For that reason, the aim of this work is to adapt the AEA as a future quality tool in the patient-centred care in orthopaedic technology to preserve sustainable the mobility of unilateral leg amputees.

## 2 Material and Methods

The proposed future quality tool consists of various measurement systems which have been proven in similar use cases [3, 4, 5]. The AEA system BoneDiaS® (Mobile System V3, broadband piezo ceramic sensor, 50-100 kHz) allows

***Joerg Subke:** THM University of Applied Sciences, Wiesenstraße 14, Gießen, Germany, joerg.subke@lse.thm.de
**Adeline Keller, Hermawan Hermawan, Michael Schmeiler, Benedict Schneider, Hans-Joachim Schwalbe:** THM University of Applied Sciences, Gießen, Germany

recording of acoustic emission in the knee joint. The ground reaction forces and the kinematics of the proband are being measured with a Zebris® FDM-S force plate and two Zebris® SyncCam video cameras (1920x1080, 30fps). The cameras are used to record the frontal and the sagittal view of the movement. By means of an aluminium test rig with two grab handles the proband can support their movement using arms and hands [5]. To measure the support of the hands two S2M® sensors (10N-1kN, class 2), HBM-System QuantumX 440B, are installed at the grab handles which are placed at a height of 118 cm and are 81 cm apart. The force plate is installed on the ground in the test rig (fig. 1).

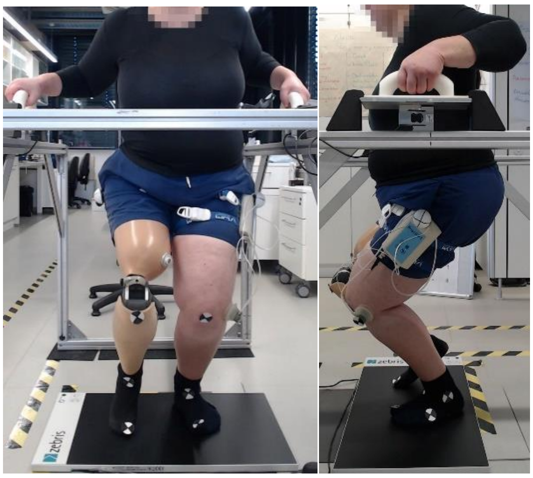

**Figure 1:** Test rig and proband with prosthesis on the force plate wearing the BoneDiaS AEA system; grabbing the handles; left - frontal view, right - sagittal view

The proband (female, 43 years old, 78 kg, 163 cm) whose right leg is amputated at the lower part of the right thigh, uses a prosthesis leg. The daily mobility is not impaired and the fitness of the proband is good (sport once a week). The proband performs three knee bends within ten seconds using two different prosthesis. The first knee prosthesis is a Össur Rheo Knee (in the following prosthesis 1) and the second knee prosthesis is a Ottobock 3R80 (in the following prosthesis 2). Both prosthesis have the same carbon foot for the normal gait.

The three knee bends within ten seconds are performed inside the test rig. This movement is performed on three different levels (flat, medial elevation ME, lateral elevation LE) under the feet to measure approximately the complete surface of the preserved knee joint. In this paper the lateral elevation case LE will be discussed. By means of two inclined boards (3° angle) the lateral sides of the feet are elevated (3mm) and the load zone of the contact between femur and tibia is shifted to the lateral side of the surface of the knee joint.

The kinematics of the frontal and sagittal video are analyzed by means of the software Tracker® e.g. joint angles and the displacements of the knee points. The inertial coordinate system in the frontal plane is placed on the right side of the proband. To assess the data the four different data sets (AEA, ground reaction forces, hand forces, video) are synchronized [4, 5]. The resulting forces and kinematic data as well as occurring AEA signals will be discussed.

# 3 Results and Discussion

## 3.1 Kinematics

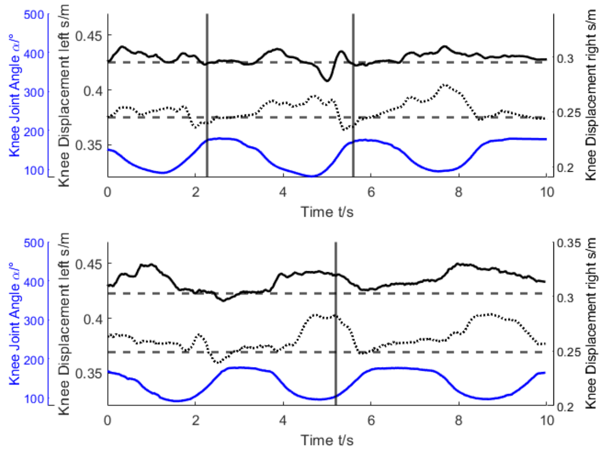


**Figure 2:** Horizontal knee displacement during three knee bends. Top: prothesis 1; bottom: prothesis 2; blue - knee joint angle; black line - left knee; black dotted - right knee (prosthesis); black vertical lines - AEA signal; black horizontal lines - level of displacement during first stance phase

In figure 2 the horizontal displacements of the knee points of the preserved leg and the prosthesis leg are presented. The sagittal knee angle serves as reference for the flexion and extension phase and the stance phase. The values of the horizontal parameters are increased in the flexion and extension phase and will decrease to the next stance phase because of the inertial system on the right side of the proband. As can be seen in fig. 2 the movement patterns of the knee bends are similar in the cases of prosthesis 1 and prosthesis 2.

In both cases the proband moves the knee points of the preserved leg and the prosthesis leg during the knee bends outward to the left side. Some variances can be seen in the case of prosthesis 1 at the end of the second knee bend where the knee point of the preserved leg is moved to the right side of the proband at t=5sec.

Overall the pattern of the horizontal trajectories shows a reproducibility of the movement in both prosthesis cases.

## 3.2 Forces

As well as the kinematics the results of the ground reaction force and the hand forces in the cases of prosthesis 1 and prosthesis 2 display characteristic patterns. In all knee bends the patterns are reproduced with light variations (fig. 3a, b).

### 3.2.1 Preserved Leg

Concerning the ground reaction force the preserved leg is primarily loaded. The prosthesis leg has only a very low load. (fig. 3, red lines). At the end of the stance phase the proband starts the drop and decelerates her body mass to the deepest point of the flexion (fig. 3, blue lines). The ground reaction force reaches its first maximum at this point. After a short instant the proband accelerates their body mass upwards. If the body mass is adequately in motion the accelerating forces are reduced. In this case the ground reaction force reaches the second maximum and the proband controls at this time the movement by means of the inertia of their mass till the next minimum of the force. At this point the stance phase is prepared by the muscular forces and the ground reaction force increases to the next maximum with a lower level in the upright stance. Depending on how the break in the stance phase is chosen by the proband there will be a peak or a plateau in the course of the ground reaction force in this phase before the next drop follows.

### 3.2.2 Prosthesis Leg

In the case of the prosthesis leg we have the inverse process in the ground reaction force. In the flexion phase the ground reaction force reaches its minimum and after the extension phase its maximum. Because there are no muscular forces at the prosthesis knee joint the prosthesis leg can only be loaded adequately in the extended position. In comparison with the preserved leg the load on the prosthesis side is less than the half of the total force.

### 3.2.3 Hand Forces

The left and right hand forces support the movement adequately in the flexion phase. The proband will stabilize the drop and the beginning of the extension movement by means of their arms and hands. In the course of the extension phase the hand forces are reduced and reach their minimum in the next stance phase.

The trajectory of the left and right hand force show that the proband does not have problems with a medial-lateral balance during the movement. The distance between the hand force trajectories is approximately constant in the movement phases and is reduced in the stance phases.

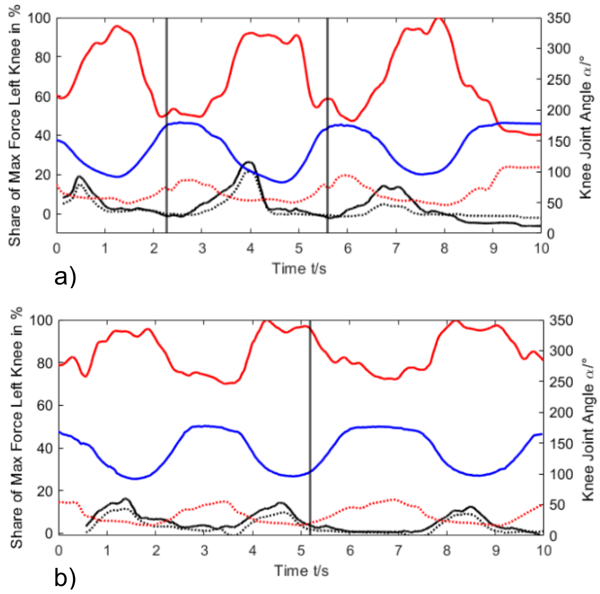


**Figure 3:** Three knee bends (LE); blue - knee angle; red - ground reaction force (line left leg, dotted right leg); black - hand force (line left hand, dotted right hand); black vertical lines - AEA-signals; a) prosthesis 1, b) prosthesis 2

## 3.3 Acoustic Emission Analysis AEA

The data of the acoustic emission analysis show two AEA signals in the case of prosthesis 1 and one AEA signal in the case of prosthesis 2. In both cases the source of the signals are discontinuities in the movement and loads of the knee joint. The source of the signals in the case of prosthesis 1 are a change in the friction in the knee joint between femur and tibia. The signals occur at the end of the extension phase of the first and second knee bend at t=2.3 sec and t=5.6 sec (fig. 3a). At these times the proband is locking the joints for the upright stance. A short instability in the locking process will cause a sticking friction in the knee joint and a stick-slip signal with two or more characteristic sequences of amplitudes will occur (fig. 4c, d). The source of the signal in the case of prosthesis 2 is a change in the flow of the joint fluid during the extension phase of the second knee bend at t=5.2 sec. The flow will change his state from laminar to turbulent and back by the change in the acceleration of the body mass after the deepest point of the flexion (fig. 3b and fig. 5). All things considered the three AEA signals show discontinuities in the movement but no lesions of the cartilage of the knee joint.

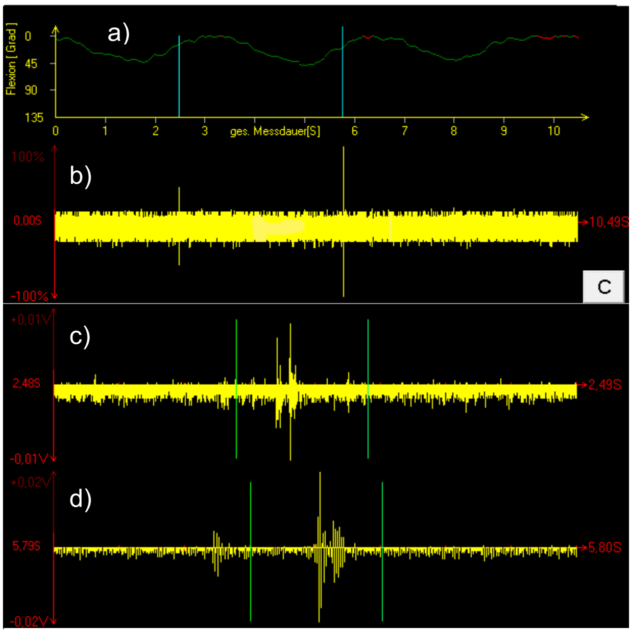


**Figure 4:** AEA during three knee bends with prothesis 1; a) angle of the three knee bends as recorded with BoneDiaS, b) overview of recorded AEA, c) signal 1, d) signal 2

# 4 Conclusion

The results of these experiments show a good reproducibility of the forces and the kinematic behavior of the proband using two different prosthesis legs. The patterns of the different kinetic parameters recur with light variations in all knee bends. A change of the prosthesis in the experiment will produce similar characteristic patterns of the trajectories of the forces and kinematics during the movement phases. The trajectories of the hand forces confirm their application in the flexion and extension phase to stabilize the movement.

The detected acoustic emission signals show in our case discontinuities in the dynamic of the movement and in the friction of the knee joint. In this experiment no lesion signal is detected in the knee of the preserved leg of the proband.

With regard to the results it can be concluded to have stabilized test conditions to proof the knee joint of the preserved leg of an amputee by means of the developed procedure. This will be a good base for a monitoring of the proband to control prospective changes of the state of the knee joint.

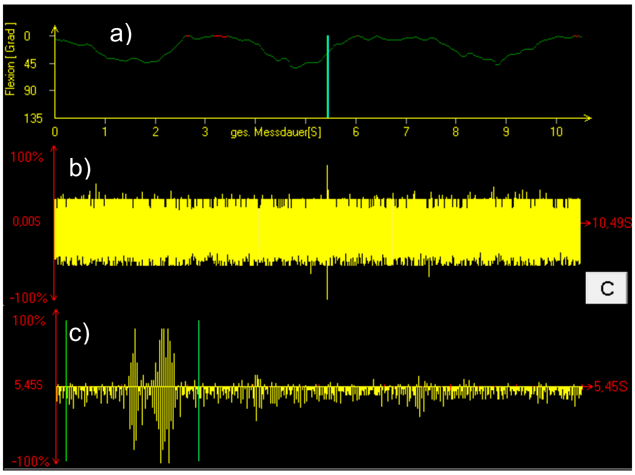


**Figure 5:** AEA during three knee bends with prothesis 2 and hand force; a) angle of the three knee bends as recorded with BoneDiaS, b) overview of recorded AEA, c) detailed view of AEA signal

**Author Statement**

Research funding: The author 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.

## References

[1] Blumentritt S, Schmalz T und Jarasch R. Die Bedeutung des statischen Prothesenaufbaus für das Stehen und Gehen des Unterschenkelamputierten. Orthopäde 2001, 30:161-168, Springer-Verlag

[2] Personal communication with S. Blumentritt, Otto Bock Health Care GmbH, Göttingen, 2009

[3] Subke J, Schneider B, Hanitz F, Krüger S, Junker HO, Schwalbe HJ and Wolf U. Clinical case study in acoustic-kinetic joint analysis: Synchronization and Evaluation of kinetic measurement data in AEA (Acoustic Emission Analysis) based diagnosis of arthritic knee joint defects (2021). Current Directions in Biomedical Engineering

[4] Subke J, Schneider B, Hanitz F and Wolf U. Acoustic-kinetic joint analysis: Synchronization and Evaluation of kinetic measurement data in AEA (Acoustic Emission Analysis) based diagnosis of arthritic knee joint defects (2021). Current Directions in Biomedical Engineering

[5] Subke J, Stelz J, Schneider B, Hanitz F and Schwalbe HJ. Development of a test rig for the diagnosis of arthritic knee joint defects in the case of lower extremity amputees in orthopaedic technology (2022)