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*Make Harmony Between Technology and Nature, and Your Mind will Fly Free as a Bird*
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# COMPARATIVE STUDY BETWEEN NORMAL AND TRANSTIBIAL GAIT

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***Abstract:*** *The purpose of this paper is to compare the gait between a normal individual and a similar sized transtibial amputee in order to establish the major differences between the loaded moments in the joints during gait. The study was conducted using experimental data taken from average individuals walking on a Kistler® force platform. AnyBody® modelling software was used to perform the inverse dynamics on a previously built model, and then the most important data was exported for a detailed comparison. Such models can be used to establish the differences in the internal energy required for walking, and as a base for prosthetic devices development.*
***Key words:*** *gait, normal, transtibial, amputee, model*

## 1. INTRODUCTION

In the case of amputees, the weight distribution over the feet when standing or walking is significantly altered, thus balance and equilibrium are being affected. Prosthetic devices can provide support for the amputated leg, but asymmetry is still present during gait (Bagley & Skinner, 1991). Data on the posture of patients and the comparison with normal, healthy persons can be very useful in the improvement of the devices or their fitting, and can speed up rehabilitation.

The ever improving area of software for body simulation and analysis offers the possibility of conducting an in-depth study on muscle activities and internal forces that are required for successful walking with an amputated limb. Better assessment of the forces and moments that occur on the joints and the major differences between normal individuals and similar sized amputees can also prove to be a vital element in the design of future equipment which allows an improved distribution of loads on the skeleton (Czerniecki & Gitter, 1996). The development of prosthetic devices taking this approach would allow them to perform everyday tasks without the fear of device failure together with the advantage of increased comfort.

Even the simplest solution with limited energy storage and return can greatly increase the comfort of disabled persons, restoring the gait to a more natural pattern. In transtibial amputees the ankle is the most critical element in such investigations, since the musculo-skeletal system is able to adapt to most defficiences and still perform in a manner similar to that expected in a healhy person. However, the rest of the joints must always be taken into consideration since oversizing of the active elements in a device might lead to extra forces being transmitted to the knee and in the long run to unwanted wear of the otherwise functional knee (Vickers et al., 2008).

Some prosthetic models include good shock absorption, with a cushion heel, but they somewhat limit the possibility of efficient gait as the active element is not powerful enough to ensure a high percentage of energy storage and return (SACH Foot). Other models show high performance, but they are costly being made entirely out of carbon fibres (Modular III). In developing countries special attention must be given to alternative methods and materials that can still have good energy storage and return (Niagara Foot).

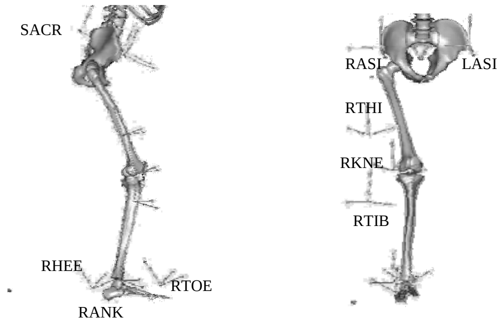

Fig. 1. Marker configuration used in the experiment

## 2. METHODS

Two subjects, a normal and an amputee with a SACH foot prostethics device were selected for this trial, with a height of 170 cm and a mass of 75 kg. Both subjects were asked to walk normally with their own shoes at a self selected speed on a flat surface and pass one leg at a time over a Kistler® force platform that was placed in the middle of the 8m walkway. The kinematic data was collected using a system of 3 high speed cameras and then digitized in the DVIDEO2004 software package developed by Laboratory of Biomechanics FEF and Institute of Computing UNICAMP. A standard marker configuration was used to ensure that the motion was recorded in a precise manner (Vaughan et al., 1999).

The synchronisation between the force plate data and the marker data was obtained employing a MATLAB® application that was specifically developed for this purpose by the authors. Furthermore, this application was used to optimize the number of points required to obtain an optimal post processed signal from the ground reaction forces. Once the amplitude of the step is selected by the user, the application establishes the first contact point of the foot; the synchronisation is obtained based on the camera output and the force plate frequency respectively.

The result is normally a number of 100 point vectors that describe the trajectory for one step along with the required force plate data in the same timeframe. The input is then converted into AnyBody® format using the routine, to emulate the pre-existing C3D data structure used by the gait routine analysis method already available with the application called “Gait Uni Miami TD Right Leg”.

The application requires the markers to show a forward motion on the x axis and that the vertical positive value be on z, while y is positive in the left of the system. Adjustments were done accordingly. The model was developed to study the human gait and is currently available in the AnyBody® repository 1.0. It uses a highly accurate leg model labelled “Twente Lower Extermity Model” composed by 159 muscles and 3 joints with 6 degrees of freedom – ankle, knee, and hip; the model is based on cadaveric data and has been fully validated (University of Twente, 2007). The marker configuration used in the standard application was modified to accommodate the study requirements (Figure 1).

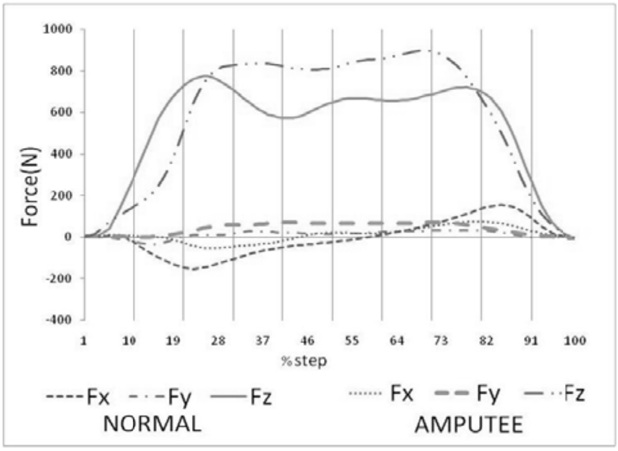


Fig. 2. Force plate data for the two subjects.

The center of ground reaction application was added to the model in x, y position which is also determined by the MATLAB® routine previously mentioned. The AnyBody® model environment.any file was modified and the ground reaction forces were introduced into the system, along with the Mz moment from the force platform.

The standard gait analysis was proved to be straight forward, and no further changes were needed in order to perform the inverse dynamics analysis. However, for the amputee analysis the muscles on the lower part of the model were excluded from the equations and the movement was imposed on a much lighter lower limb in order to simulate the presence of a transtibial prosthetics device for the next part.

## 3. RESULTS

After running the inverse dynamics, the data on moments was extracted for the ankle, knee and hip joints from the AnyBody® model. The moments for the normal gait were in consistent with the previous work (Vaughan et al., 1999), which allows the validation of the experimental set-up and the analysis. Of interest for this particular study were the moments in the forward motion, the sagittal plane, My in the coordinate system used by the experiment. In Fig. 3 A, B, C the comparison between the moments in the joints on the virtual humans is presented. The continuous line represents the gait of the amputee subject, and the dashed line – the normal person, as a reference. In a similar manner, in Fig. 3 D, E, F the difference between the angular displacements of the same joints can be observed.

The figures on angular displacements of the joints show that a good recovery of transtibial amputees is possible, the only difference is in the ankle area, as it was expected. In Figure 4a, the trends of the moment for the ankle joint flexion, the difference between an optimal system (normal gait) and the prosthetics is clear, the prosthetics releases energy in the middle of the stance but does so in an abrupt manner, unlike the normal gait where the moment increases almost linearly. The knee and the hip joints show similar patterns in both moments and angular displacements, indicating that the body adapts to the prosthetic device and the amputee manages to walk in nearly natural manner. The differences between the amplitudes of the various moments might also be influenced by the variations in individual weights of the subjects but the major differences are the result of the amputation.

The research is limited in the sense that it only involves two subjects and is solely based on a numerical simulation of the human gait. It needs to be improved by further analysis of other amputees of various sizes and with different prosthetic models. Further research should involve a thermography study of patients in order to determine the accuracy of the simulation in regards to the muscle recruitment used.

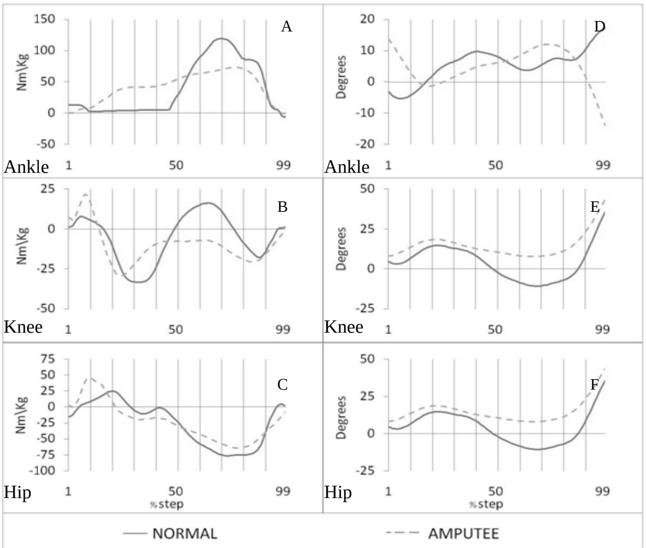


Fig. 3. A, B, C moment in the sagittal plane. D, E, F Angular displacements in joints.

## 4. CONCLUSION

Even though the results presented here are preliminary, they show that the applied methodology has a great potential to analyze amputees' gait and can be used to improve protocols related to their rehabilitation.

The ideal spring mechanism would be a device with slower release that can complete the lift of the leg much smoother to comply with the motion of the rest of the body. Future comparative studies will be conducted to prove the general applicability of the proposed method. Additionally, there is a possibility of personalization of the prosthetic devices, taking in account the stiffness modification necessary for the spring.

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