Predictive Gait Simulations of Leg Length Inequality

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***Abstract*—Predictive gait simulations offer valuable insights into the biomechanical dynamics of human movement and have significant implications for clinical practice and technological innovation. In this study, we conducted predictive gait simulations to investigate the effects of leg length inequality on biomechanical parameters. We created predictive simulations to predict knee angle, ankle angle, hip flexion, hip adduction, and hip rotation for scenarios with various leg length differences. We compared our simulation results with the experimental data obtained using IMUs. While our results showed promising accuracy, deviations between simulation and experimental data were observed, indicating opportunities for further refinement and improvement. Future research directions include fine-tuning simulation parameters, integrating advanced machine learning techniques, and exploring alternative data sources such as optical motion capture systems instead of IMUs.**

I. Introduction

Leg length inequality (LLI) is a common musculoskeletal condition that can significantly affect an individual's gait pattern and biomechanics [1]. In this study, we use predictive gait simulations to explore the effects of LLI on various biomechanical parameters. In this report, we present the predicted knee angle, ankle angle, hip flexion, hip adduction, and hip rotation for scenarios with different LLI.

Predictive simulations were successfully applied to investigate the impact of midsole materials on the energy cost of running. This approach laid the groundwork for future applications of predictive simulations in diverse areas, such as assessing the performance of different midsole materials, prostheses, and other biomechanical interventions[2].

The methodology employed in this study involved predictive gait simulations, a tool that allows for the simulation of human movement under various conditions. Specifically, we utilized a simulation framework developed at the Machine Learning and Data Analytics Lab, Erlangen (MaD Lab), which makes use of optimal control techniques and IPOPT optimization to simulate human gait [3]. The model utilized in these simulations is based on the OpenSim platform, a widely used software for biomechanical modeling and simulation [4].

Understanding the biomechanical consequences of LLI is crucial for clinicians and researchers alike, as it can inform treatment strategies and interventions for individuals affected by this condition. By employing predictive gait simulations, we can gain valuable insights into the complex interactions between musculoskeletal structures and movement patterns, ultimately advancing our understanding of LLI and its implications for human locomotion [5].

In the subsequent sections of this report, we will detail the methods employed in the simulations, present the results of our analysis, and discuss the implications of our findings. Through this investigation, we aim to contribute to the growing body of knowledge surrounding LLI and its biomechanical effects on gait.

II. Methods

The predictive gait simulations were conducted using experimental data obtained from at the motion lab under the supervision of Prof. Marcel Betsch at Uniklinikum Erlangen. The data consisted of inertial measurement unit (IMU) data collected from various parts of the body.

To prepare the data for simulation, we initially divided it into gait cycles. This was achieved by utilizing the accelerometer recordings along the dorsal axis of the right foot. Peaks in the accelerometer data were detected to find the boundaries of individual gait cycles. Subsequently, ensemble averaging was applied to the individual gait cycles for each variable. This preprocessing step ensured consistency and accuracy in the input data for the simulations.

The simulations were conducted using a simulation framework developed at the Machine Learning and Data Analytics Lab, Erlangen (MaD Lab). This framework makes use of optimal control techniques and IPOPT optimization to simulate human gait. The model for the simulations was created on OpenSim, a widely used software for biomechanical modeling and simulation.

To investigate the effects of LLI on biomechanical parameters, simulations were performed for three scenarios: equal leg length, 2 cm longer right leg, and 4 cm longer right leg. To induce LLI in the simulations, the contact point of the right foot with the ground was varied, mimicking the asymmetry observed in individuals with LLI. By manipulating this parameter, we aimed to investigate how alterations in leg length may impact the biomechanics of gait. In the simulations, six variables were tracked during the simulations for analysis: hip flexion, knee angle, and ankle angle (for both left and right).

Visualization of the simulation results was carried out by plotting the ground truth data alongside the simulated data for comparison. This allowed for a comprehensive assessment of the predictive capabilities of the simulation framework across various biomechanical parameters such as knee angle, ankle angle, hip flexion, hip adduction, and hip rotation.

III. Results

After running the simulations for the equal leg length case, the 2 cm longer right leg case, and the 4 cm longer right leg case, we obtained results for several biomechanical parameters, including knee angle, ankle angle, hip flexion, hip adduction, and hip rotation. To evaluate the accuracy of our simulations, in Figures 1-4, we plotted each set of simulation results alongside the corresponding ground truth measurements on the same plot for each variable.

In these plots, the ground truth measurements are represented by solid lines, while the simulation results are depicted by dashed lines. Additionally, we employed a color scheme to distinguish between different leg length scenarios: blue lines correspond to the equal leg length case, green lines correspond to the 2 cm longer right leg case, and red lines correspond to the 4 cm longer right leg case.

Figure 1 illustrates the results for left knee and ankle angles, Figure 2 illustrates the results for right knee and ankle angles, Figure 3 illustrates the results for left hip flexion, hip adduction, and hip rotation, and Figure 4 illustrates the results for right hip flexion, hip adduction, and hip rotation.

Moreover, stick figures are showed in Figure 5 to visually represent the results of the simulation. These figures display all the frames overlaid on top of each other, providing a comprehensive visualization of the simulated gait dynamics.

IV. Discussion

Our predictive simulations have demonstrated promising results in predicting biomechanical variables such as knee angle, ankle angle, hip flexion, hip adduction, and hip rotation across different leg length scenarios. In most cases, the simulation results closely match the ground truth measurements, indicating the efficacy of our simulation framework.

However, it is important to acknowledge instances where deviations between simulation results and ground truth measurements were observed. These deviations could arise from various factors, including inaccuracies in the simulation parameters and initial conditions. By fine-tuning these parameters and adjusting the initial conditions of the simulation, we anticipate that even better results can be achieved, potentially reducing discrepancies between simulation and ground truth data.

Furthermore, the use of IMU data for simulation may introduce limitations that could affect the accuracy of the results. IMU data, while convenient for capturing motion in real-world settings, may not capture subtle nuances in movement with the same precision as optical motion capture systems. The inherent noise and limitations of IMU sensors could contribute to discrepancies between simulated and actual biomechanical variables. Looking ahead, we are optimistic about the potential for improved simulation accuracy by leveraging optical motion capture data instead of IMU data.

In conclusion, while our predictive simulations have shown promising results, there is still room for refinement and improvement. By addressing the aforementioned factors and exploring alternative data sources such as optical motion capture, we aim to further enhance the accuracy and reliability of our simulation framework for biomechanical analysis.

V. Summary and Outlook

In this study, we successfully conducted predictive gait simulations to investigate the effects of LLI on biomechanical parameters. Our simulations predicted knee angle, ankle angle, hip flexion, hip adduction, and hip rotation across various leg length scenarios, demonstrating agreement with ground truth measurements.

Looking ahead, there are several opportunities for further research and development. Refining our simulation framework by fine-tuning parameters and integrating advanced machine-learning techniques could enhance predictive capabilities. Additionally, exploring alternative data sources such as optical motion capture systems may improve simulation accuracy.

In conclusion, our study represents a significant advancement in predictive biomechanics. By pushing the boundaries of computational modeling and simulation frameworks, we aim to improve our understanding of human movement and contribute to advancements in clinical practice, technological innovation, and interdisciplinary research.

Acknowledgment

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I am also grateful to Prof. Dr. Marcel Betsch for generously providing the experimental data used in this study and for insightful discussions on the interpretation of the results. His expertise and collaboration greatly enriched the quality of the research outcomes.

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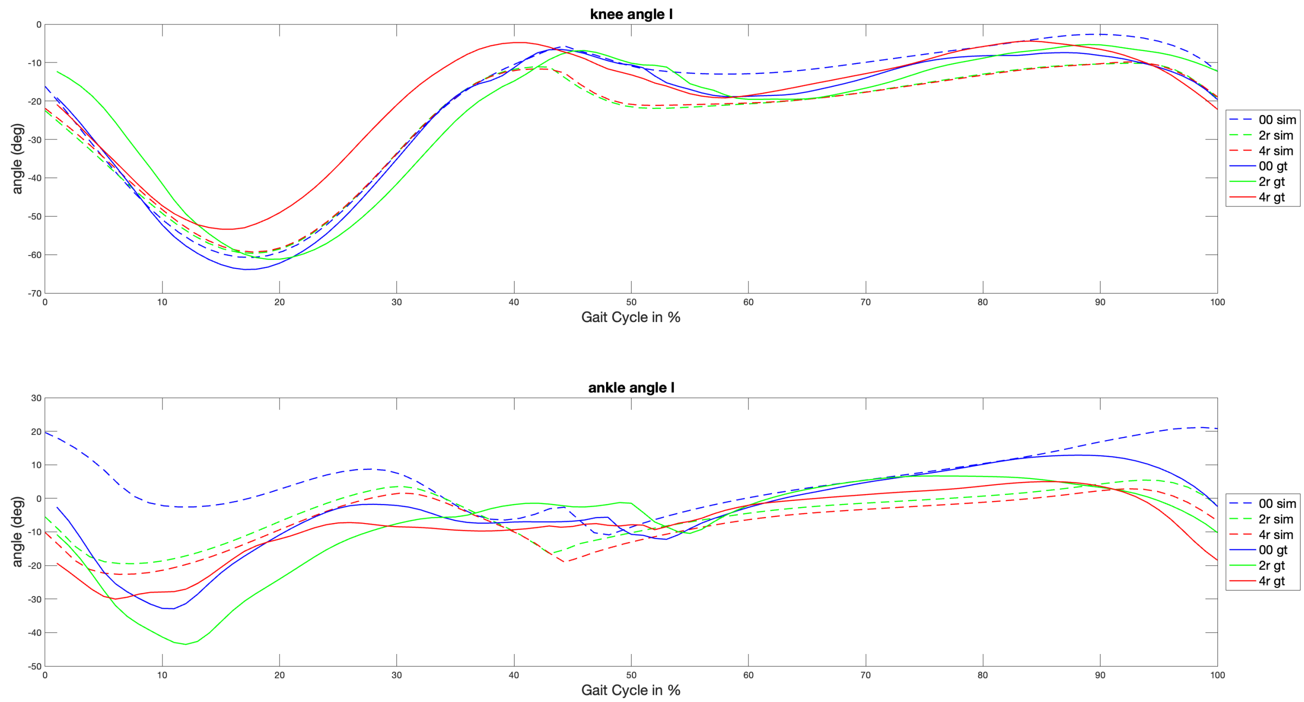

Fig. 1. Comparison of simulation and ground truth of left knee and ankle angles during one gait cycle where angle values are measured in degrees. Continuous lines represent the ground truth data, while dashed lines represent the simulation results. Blue lines correspond to the equal leg length case, green lines correspond the 2 cm longer right leg case, and red lines correspond the 4 cm longer right leg case.

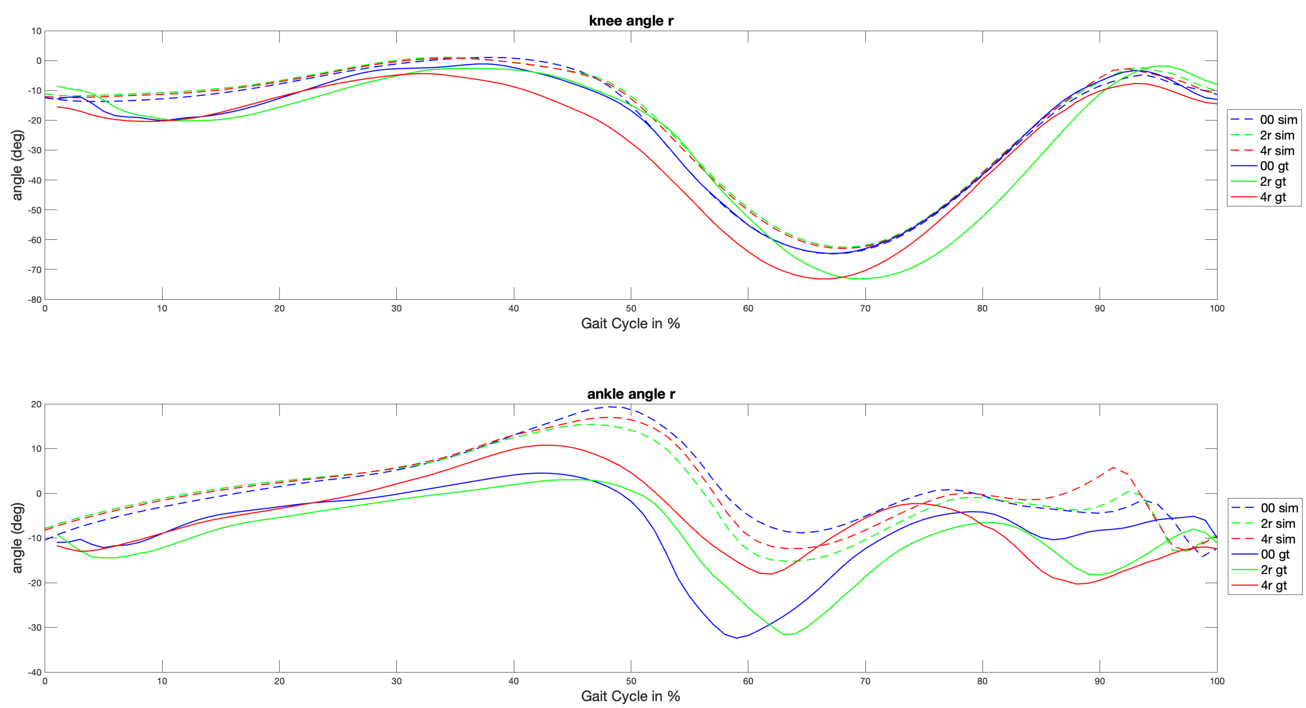

Fig. 2. Comparison of simulation and ground truth of right knee and ankle angles during one gait cycle where angle values are measured in degrees. Continuous lines represent the ground truth data, while dashed lines indicate the simulation results. Blue lines correspond to the equal leg length case, green lines represent the 2 cm longer right leg case, and red lines correspond the 4 cm longer right leg case.

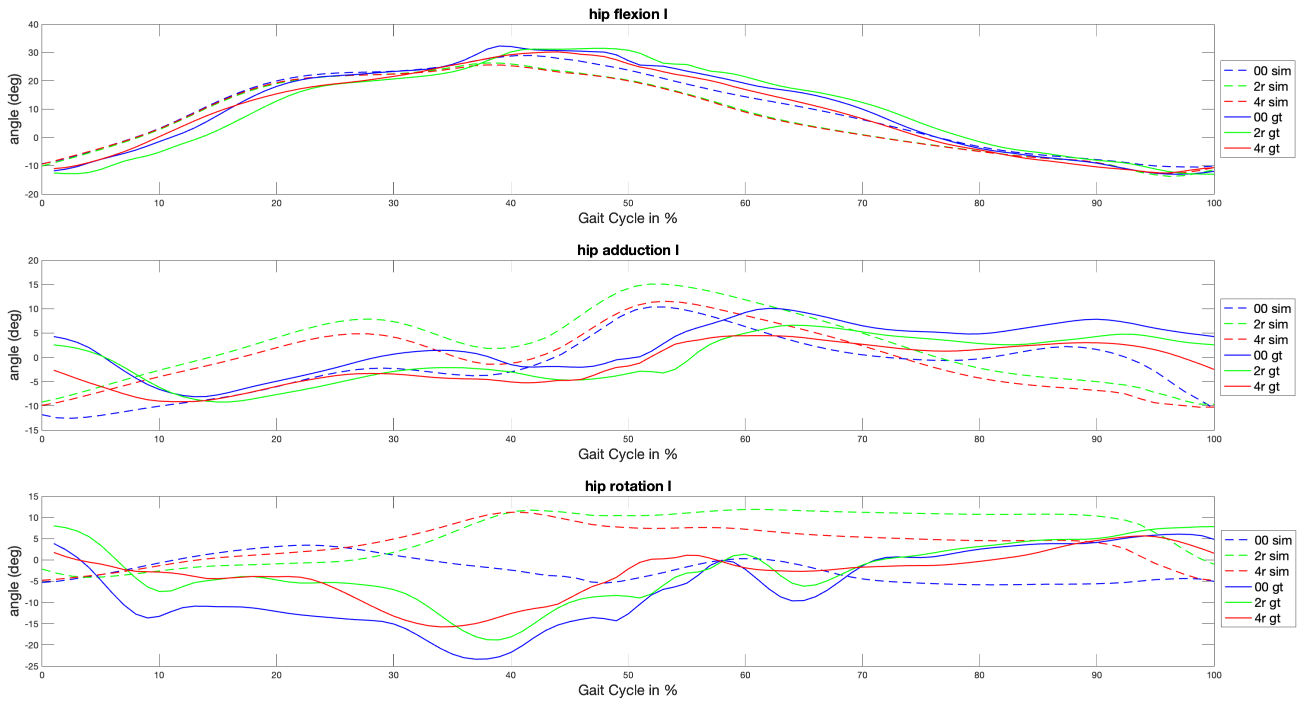

Fig. 3. Comparison of simulation and ground truth of left hip flexion, hip adduction and hip rotation during one gait cycle where angle values are measured in degrees. Continuous lines represent the ground truth data, while dashed lines represent the simulation results. Blue lines correspond to the equal leg length case, green lines correspond the 2 cm longer right leg case, and red lines correspond the 4 cm longer right leg case.

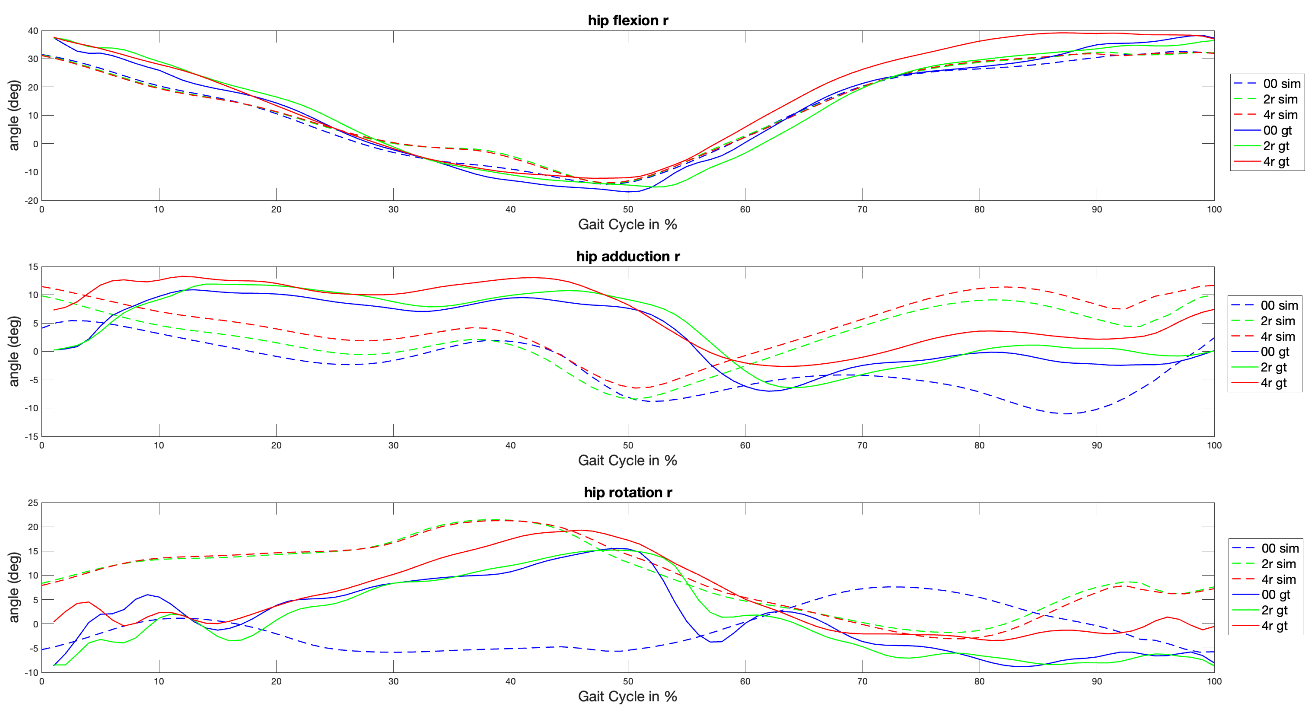

Fig. 4. Comparison of simulation and ground truth of right hip flexion, hip adduction and hip rotation during one gait cycle where angle values are measured in degrees. Continuous lines represent the ground truth data, while dashed lines represent the simulation results. Blue lines correspond to the equal leg length case, green lines correspond the 2 cm longer right leg case, and red lines correspond the 4 cm longer right leg case.

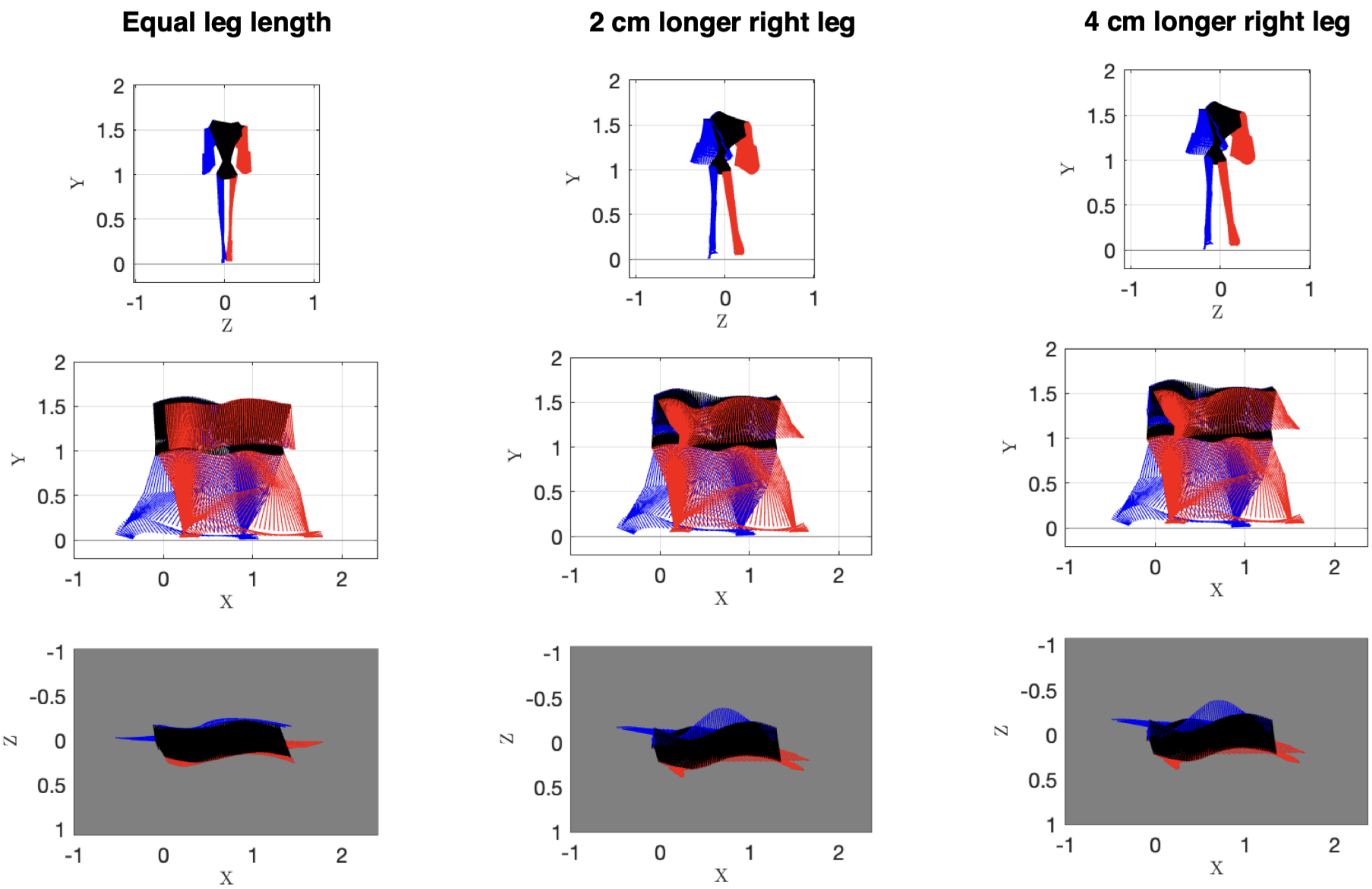

Fig. 5. Stick figures of the simulation to visually represent the results of the simulation. On the left is the stick figures for the equal leg length case, in the middle is the stick figures for the 2 cm longer leg length case, on the right for the 4 cm longer leg length case.