발가락 관절이 대퇴의족의 보행에 미치는 생체역학적 영향

Biomechanical Impacts of Toe Joint With Transfemoral Amputee Using a Powered Knee-Ankle Prosthesis

Keywords: Powered prosthesis(전동 의족), Toe joint(발가락 관절), Kinematics (기구학), Biomechanics (생체역학)

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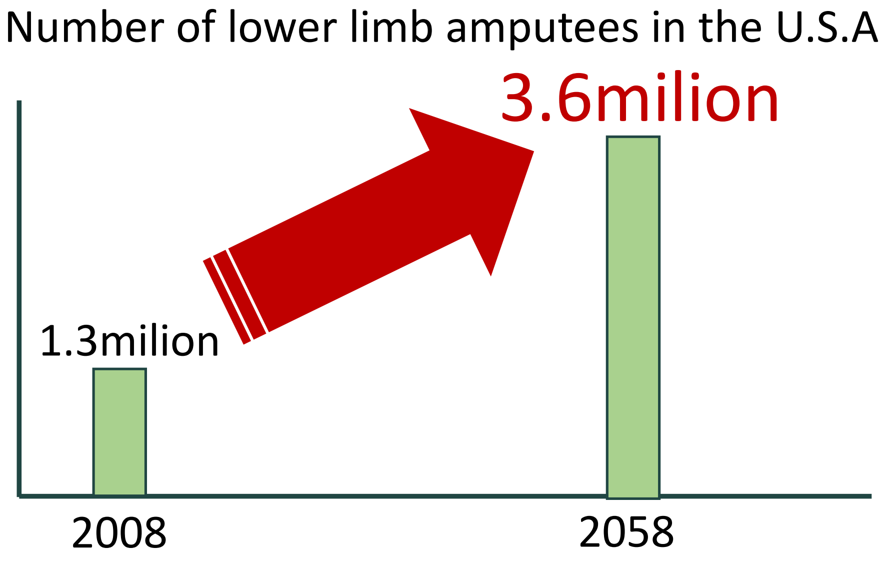
- **Background**



Technologies such as robotic prostheses are essential for the quality of life of lower limb amputees.

- **Human-like walking for the powered prosthesis**

Characteristic of Human-like walking

→ **Push-off / Heel-off / Heel-Strike / Foot-drop**

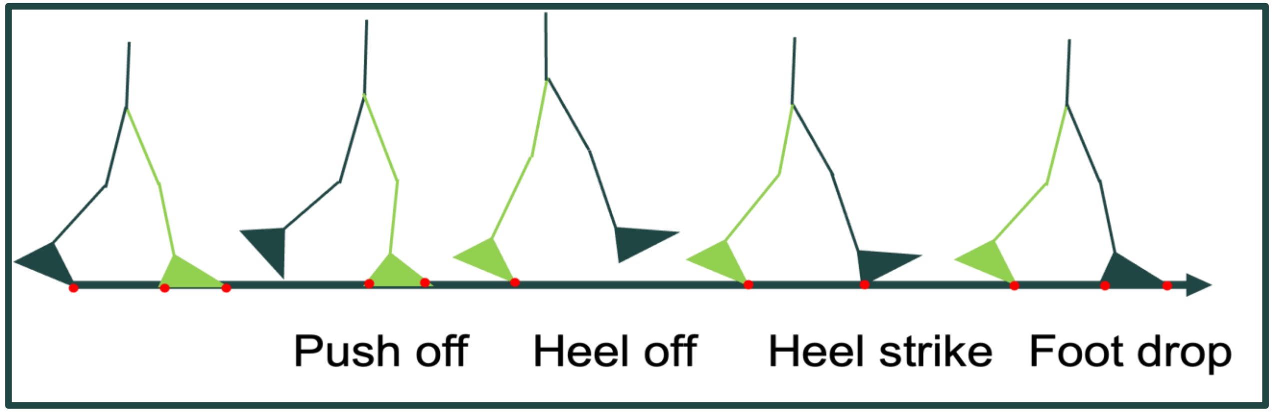


Figure 1. Gait Progression

Well-made robotic prosthesis

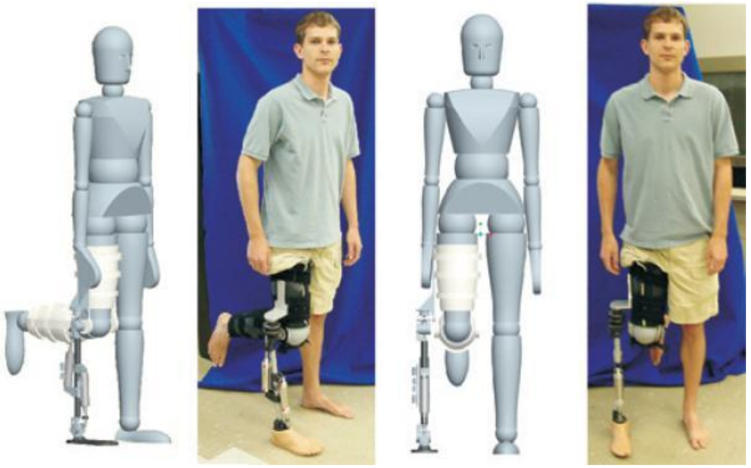
↓

Well-followed human's walking characteristic

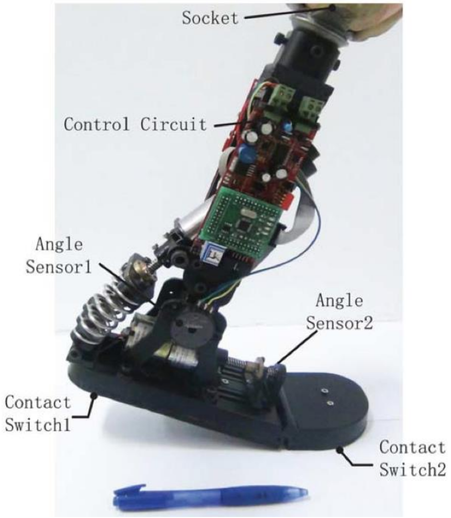
More Symmetric Walking

- **Prior Research**

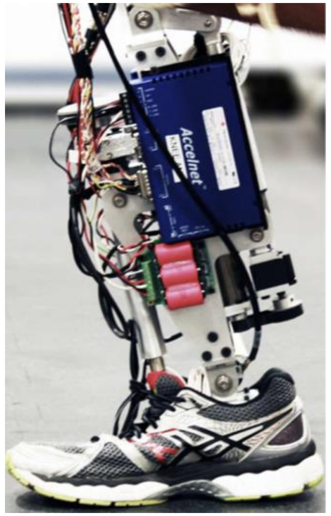
BiOM bionic lower leg



Sub and Goldfarb (2006)



Zhu et al, (2014)



Quintero et al., (2018)

none have investigated the impact of toe-joints on the performance of powered knee-ankle prosthesis.

- **Research Overview**

- **In this study,**

Analyzed the use of an actuated knee-ankle prosthesis with a toe – joint for transfemoral amputees.

How three different toe-joint stiffness impact spatiotemporal measures, kinetics, and kinematics.

- **Hypothesis**

The lower stiffness spring will provide less push-off power during walking

compared to stiffer and rigid stiffness foot,

- Equipment Overview

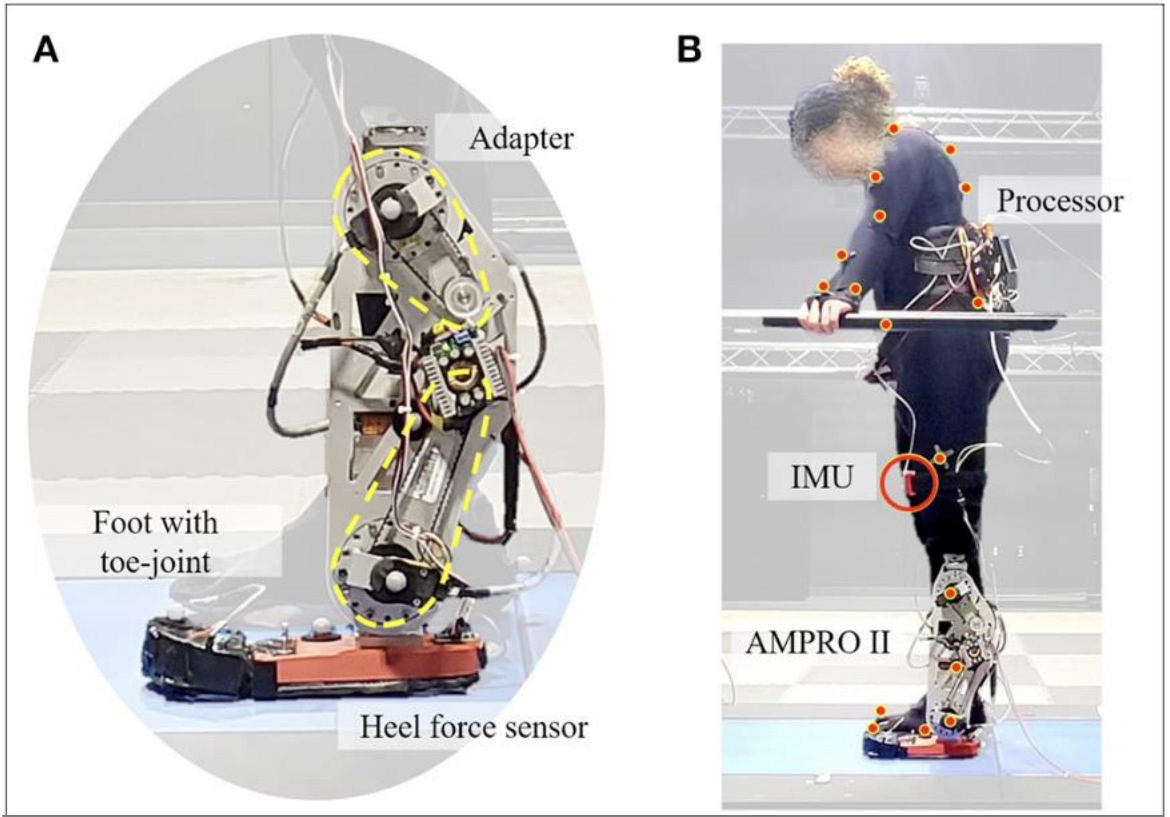


Figure3. Experiment setup: (A) is the powered transfemoral prosthesis, AMPRO 2, (B) shows the amputee walking with AMPRO 2 in the motion capture environment

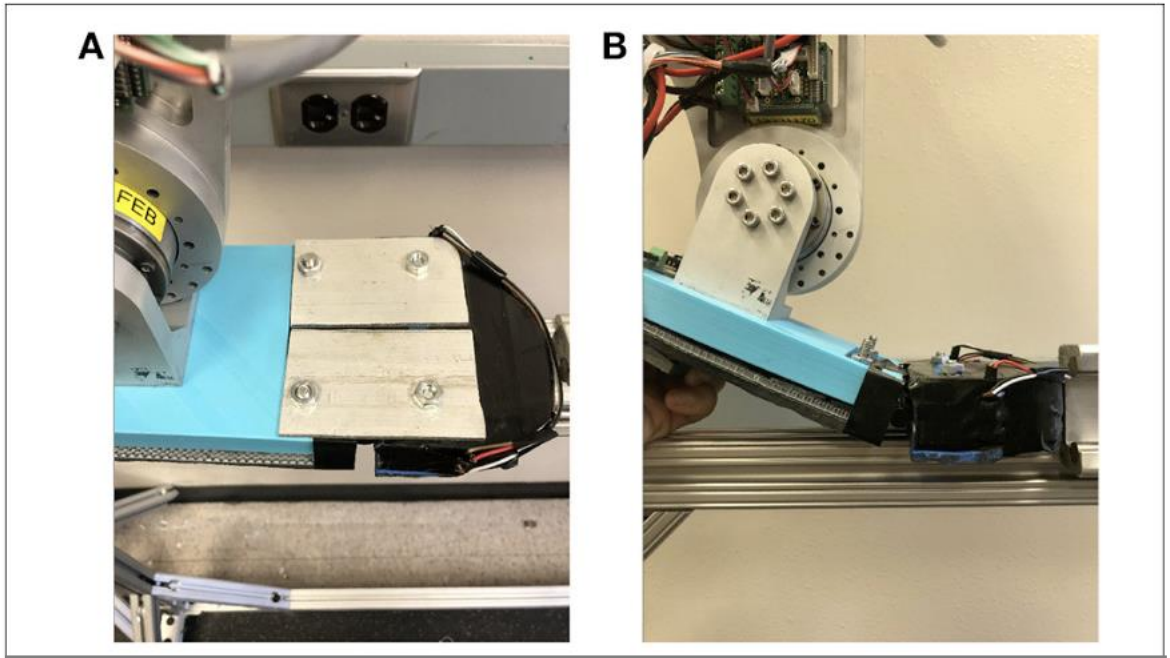


Figure4.|(A) AMPRO 2 with locked rigid Foot, (B) AMPRO 2 with Fixed foot

Stiffness of Strip

0.83Nm/deg , 1.25Nm/deg , rigid joint

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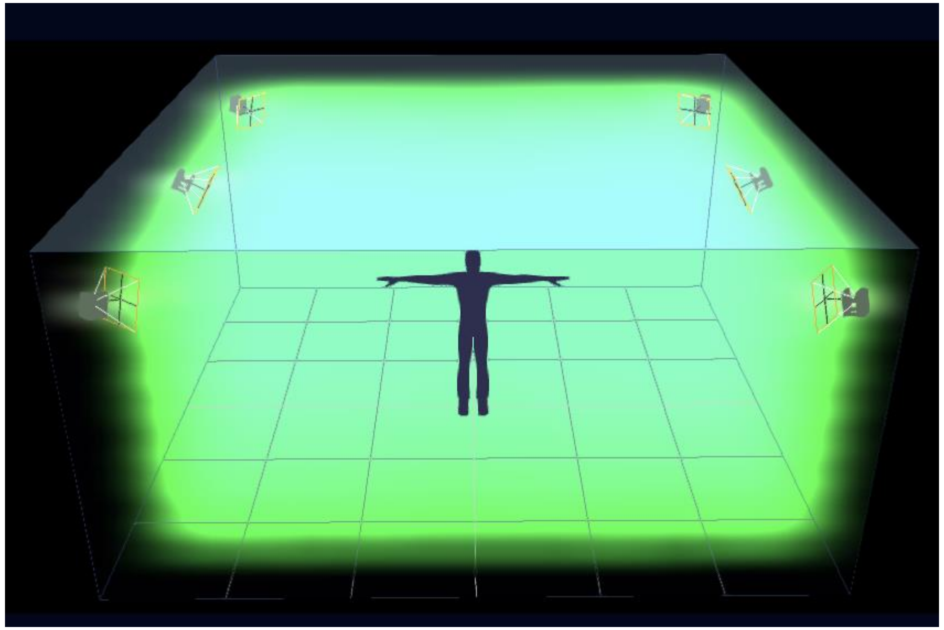
- Equipment Overview



44 motion capture cameras (Vantage, Vicon Motion System Ltd., Oxford UK) was used

Data were collected 100 Hz

A force-sensing tandem instrumented treadmill

(AMTI, Watertown, MA, USA).

Data were collected 1000 Hz

- Experiment Overview

- A participant: Unilateral transfemoral amputee (female, 164cm, 66kg w/o prosthesis)

Protocol

- 8 practice sessions were conducted
- Most comfortable walking speed: 0.67m/s
- Three joint stiffness condition

  0.83 Nm/deg , 1.25Nm/deg , Infinite (Rigid)

- Each walking trials : 90s
- Breaks between foot change: 10min
- It is allowed to take a longer rest if requested*

Data Processing

- All post-processing was done in

  Vicon Nexus & Visual 3D

- Marker trajectory & force data

Vicon Nexus with low-pass third order butter worth filter at 10 and 20 Hz

- Hip, Knee, and ankle joint angle, moment, power

Calculated in the sagittal plane using Visual 3D

- Data Processing

Data Processing

*spatiotemporal metric : total step length, step time, swing time, and stance time.

- Symmetry index (SI)

$$SI = \frac{(X_P - X_I)}{0.5(X_P + X_I)} * 100$$

X_P: spatiotemporal* metric on the prosthesis side

X_I: spatiotemporal* metric on the intact side

- One-way repeated-measures ANOVA : For all spatiotemporal metrics

- Two-tailed paired t-test

If the above showed significant impact of toe-joint stiffness, For all combination of toe-joint stiffness

- Spatiotemporal Data

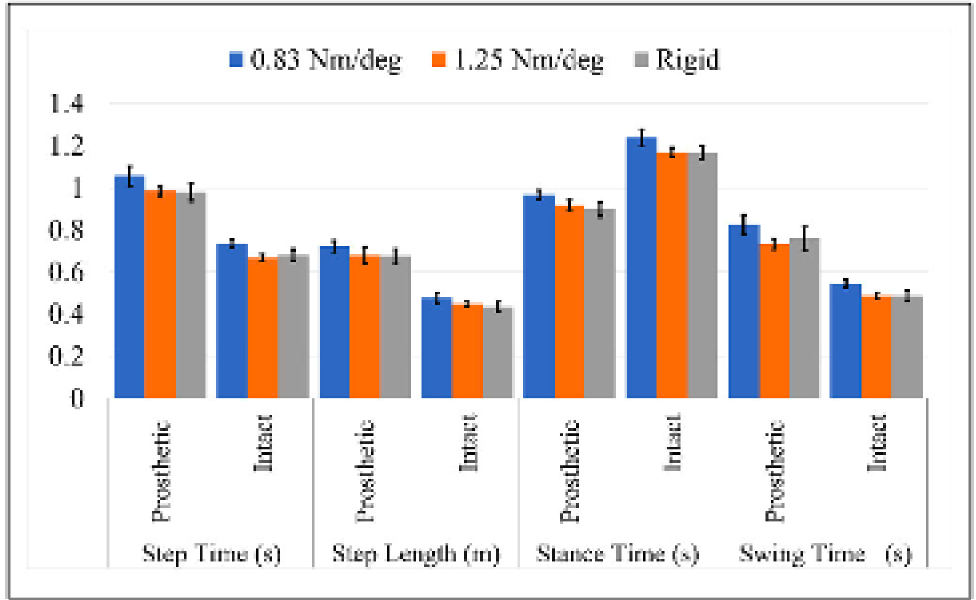


Figure5.|Spatiotamporal metrics for intact and prosthesis legs

- **Prosthesis side**
  significant impact on toe-joint

	Step time	Stance time	Swing time	Step length
P-value	**P< 0.001**	**P= 0.001**	**P= 0.001**	**P= 0.02**

- **Intact side**
  significant impact on toe-joint

	Step time	Stance time	Swing time	Step length
P-value	**P< 0.001**	**P< 0.001**	**P< 0.001**	**P< 0.02**

- Spatiotemporal Data

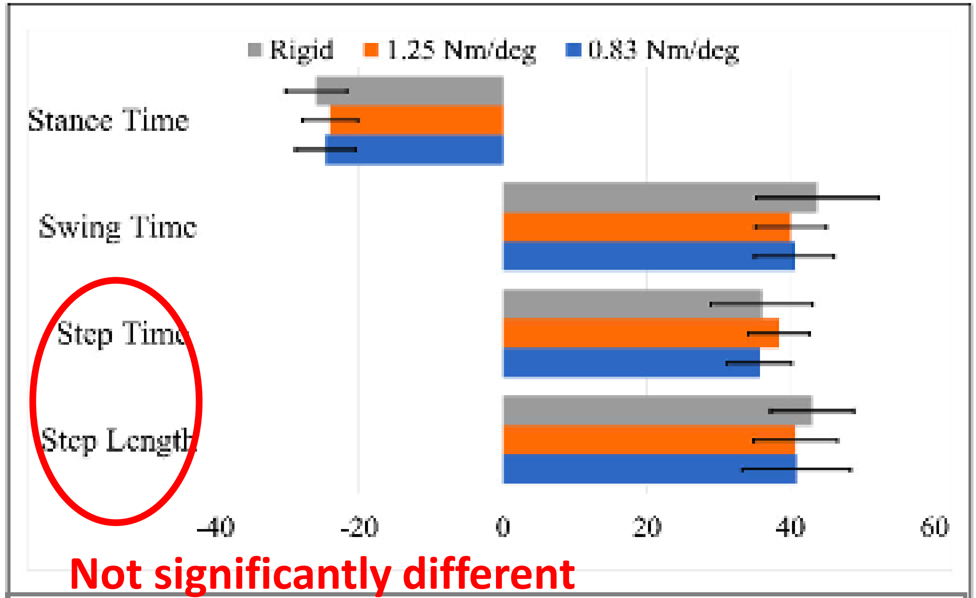


Figure6. | Symmetry Index (SI) for spatiotemporal metrics.

- SI index for all spatiotemporal values not to very significantly with toe joint stiffness

$P > 0.34$

- Kinetics and Kinematics

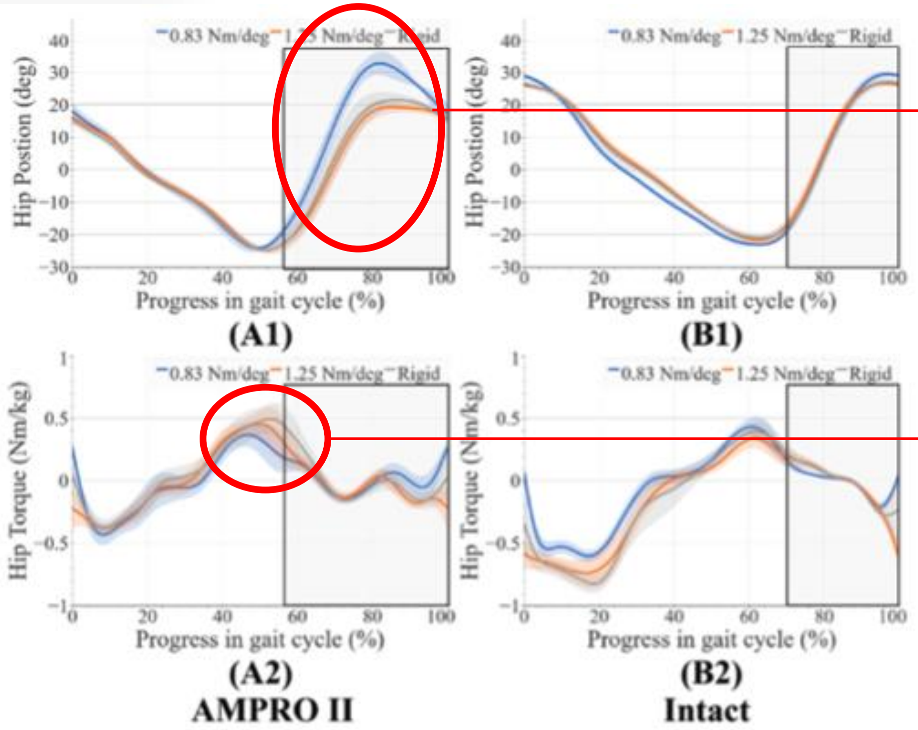


Figure7.| **A1)** Hip angles on prosthesis side, **(A2)** hip moments on prosthesis side, **(B1)** hip angles on intact side, **(B2)** hip moments on intact side, average swing phase for each case is boxed in the gray

Hip flexion at the end

0.83Nm/deg – Rigid joint stiffness : 10 degrees greater

0.83Nm/deg – 1.25 Nm/deg joint stiffness : 12 degrees greater

The Maximum hip torque

Increased with stiffness

- Kinetics and Kinematics

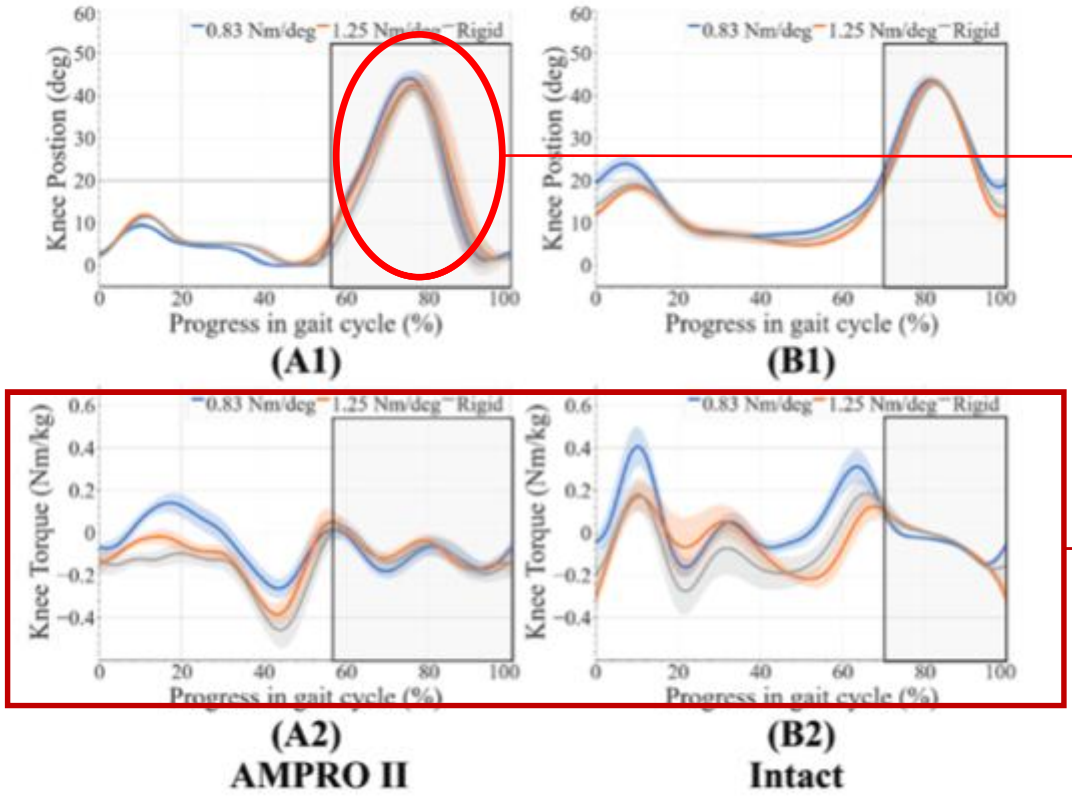


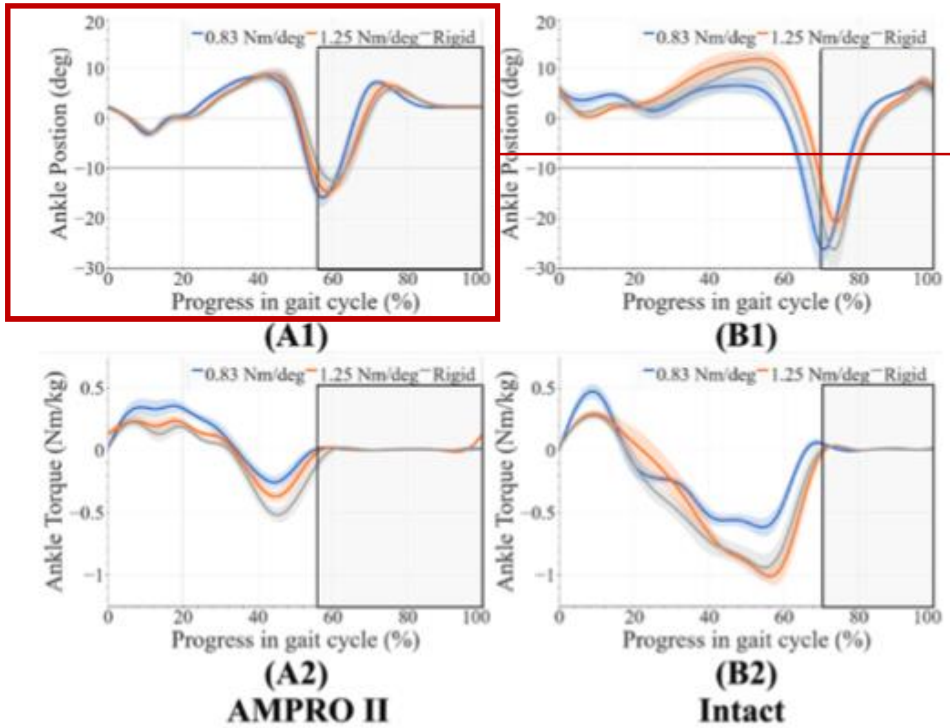
Figure8.|**(A1)** Knee angles on prosthesis side, **(A2)** knee moments on prosthesis side, **(B1)** knee angles on intact side, **(B2)** knee moments on intact side, average swing phase for each case is boxed in the gray.

Very few changes in knee range of motion

On the Prosthesis / Intact side

Greater flexion torque in early stance when using 0.83 Nm/deg

- Kinetics and Kinematics



On the Prosthesis

Ankle range of motion was very similar ($\pm 2^{\circ}$)

Figure9.|**(A1)** Ankle angles on prosthesis side, **(A2)** ankle moments on prosthesis side, **(B1)** ankle angles on intact side, **(B2)** ankle moments on intact side, average swing phase for each case is boxed in the gray.

- Kinetics and Kinematics

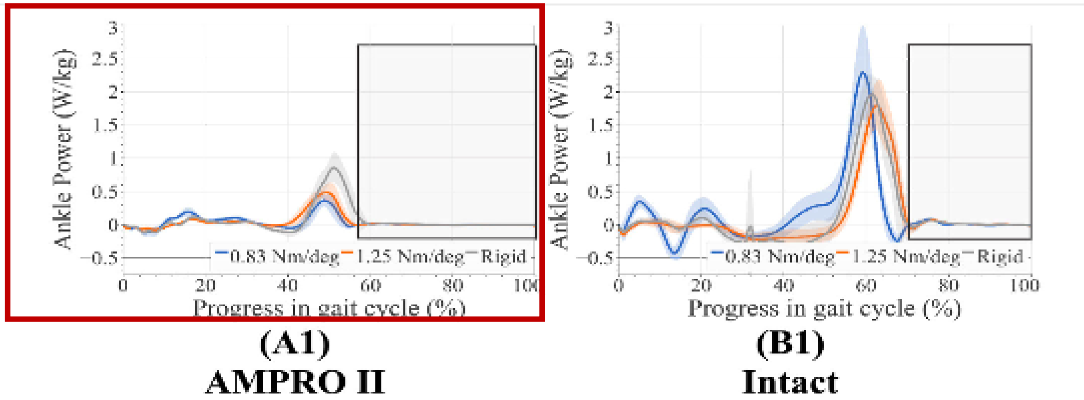


Figure10.|**(A1)** Ankle power on prosthesis side, **(B1)** ankle power on intact side, average swing phase for each case is boxed in the gray.

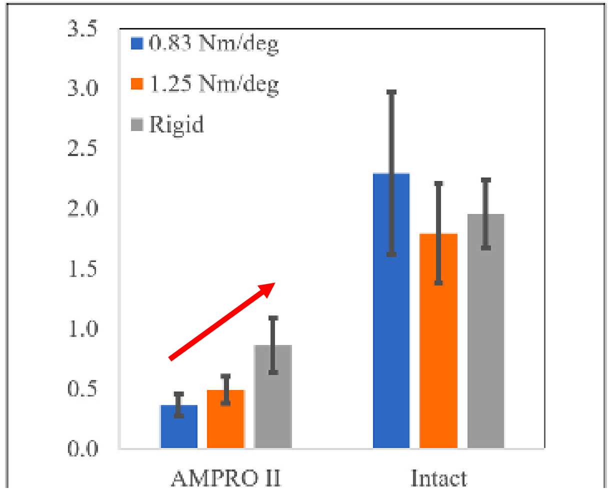


Figure11.|**Push-off ankle power**

On the prosthesis side

Peak power did increase with stiffness

- Discussion

- When using a toe joint of 0.83 Nm/deg, the stance time appeared longer in Step

  → However, This longer stance did not produce a more symmetric gait(Figure 6)

- In the case of 0.83 Nm/deg, there were some compensatory motions that resulted

  → the resulting ankle push-off torque and power were lower compared to those of 1.25 Nm/deg and rigid joint stiffnesses. (Figure 11)

  → participants to feel less stable during heel strikes and push-off

- Of the three toe joints, the results of the 1.25 Nm/deg case are slightly more symmetrical

  → The use of 1.25 Nm/deg toe joints can indicate that it can help reduce full body overload

- Take home message

- A toe joint with a suitably selected stiffness can reduce the loading on the intact leg.

- To replicate the benefits of the human toe-joint, more stiffness and toe-joint design need to be explored.

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