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Study of Knee and Hip Joints' Moment Estimation by Biomechanical Simulation During Various Motion Changes

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***Abstract*—In this study, biomechanical parameters of lower limb joints due to motion changes have been estimated to develop the 3-D model that can analyze dynamic gait simulation for wearable walking assistant robot. Motion data which include stair up and sit-to-stand condition of human motion upon normal person with no nervous system and musculoskeletal disease was obtained from 3-D motion analysis system. As a result, it was observed that maximum torque value of hip joint (1.26Nm/kg) was much higher than knee joint (0.49Nm/kg) during stair up stage in sagittal plane. On the other hand, maximum torque value of knee joint (0.72Nm/kg) was higher than hip joint (0.18Nm/kg) during sit-to-stand stage using walker. And maximum torque value of knee joint (1.20Nm/kg) was higher than hip joint (0.87Nm/kg) during sit-to-stand stage with no constraints. In this study, biomechanical characteristics of lower limb joint upon various conditions were presented and these data can be applied to biomedical research field that include wearable walking assistant robot.**

***Index Terms*—Dynamic Simulation, Gait Analysis, Hip Joint, Knee Joint, Torques**

I. Introduction

Rehabilitation techniques are increasingly being researched due to the increase of paraplegia caused by industrial disasters, diseases and accidents. For patients with lower limb disability, wheelchair, walking stick, crutch, walker and RGO (Robotic Gait Orthosis) are being used commercially as a walking assistant device (A.F.O) and these devices have been extremely useful in prevention of congenital, minimization of osteoporosis and improvement of the circulation of the blood.

In consequence of this advantage, previous study has been researched to develop the wearable walking assistant robot that can help various walking conditions that include stair and slope way climbing, sitting and standing. At the same time, estimating the safety and validation of wearable walking assistant robot is difficult because of high cost, long period of development and limited clinical trial and this leads to the unfriendly condition to research the effective developing system

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This paper focuses on the optimization of biomechanical parameters for lower limb joint of wearable walking assistant robot by estimating joint moment through analyzing motion changes due to 3-D motion analysis and 3-D computer model.

Fig. 1 Plug-in-Gait Marker set

II. Methodology

A. *Motion Capture Method*

A.1 Test Set up

3-D motion analysis system (Motion Analysis, USA) and Plug-in-marker set were used for motion capture test. (Table 1)

To record exercise of upper and lower body in human anatomy position, total 31 markers were attached and static pose test was conducted. After then, 8 markers were removed for dynamic pose test. (Fig. 1)

A.2 Motion Test

Spatial motion of total 23 markers was measured during stair climbing and sit-to-stand condition and these markers were adapted to input values in simulation process. (Fig. 2, 3)

Input values draw trajectory from space to each direction of X, Y, Z and markers of computer model can get motion data such as an action originate from real human body changes along these trajectories.

B. *Human Body Modeling*

3-D computer analysis was executed by using motion test result of human body experiment and musculoskeletal model was formed by using ADAMS (MSC Software corp., USA) and BRG.LifeMOD 2005.5.0(Biomechanics Research Group, Inc., USA). Experimental subject (27 years old with 178 height and 83 kg weight) performed this test . (Fig. 4)

Table 1 3-D Motion Analysis System

Kind	Force Plate	Thermo Camera	10mm Reflection Marker	CCD Camera	Data Processor	PC
Number	4	8	31	2	1	1

Table 2 Stair Size

Composition	Length	Height	Width	Characteristic
Step 1	88 cm	22.2 cm	30 cm	Composition to Two
Step 2	88 cm	28 cm	40 cm	Stairs

Table 3 Chair Size

Length	Height	Width	Characteristic
40 cm	46 cm	4 cm	no support and sleeveless coat

C. Stair and Chair Modeling

3-D modeling process was performed by measuring parameters based on ADAMS (MSC Software corp., USA) (Table 2, 3, Fig. 5)

D. Boundary Condition

Musculoskeletal model was implemented through path of markers for creating model.

D.1 Stair up

Fig. 6 shows image that position and exercise trainee (Motion Agents) of reflection marker which is seen in Fig. 1 are embodied, and backward kinetic analysis (Inverse Dynamics) was conducted based on this model. [1] Boundary condition between human body and ground was applied for walk in the ground by contact between stairs and sole of the model's foot.

Also, boundary condition between human model and stairs was applied in order to climbing the stairs such that not affected by gravity by contact between stairs and sole of the human model's foot

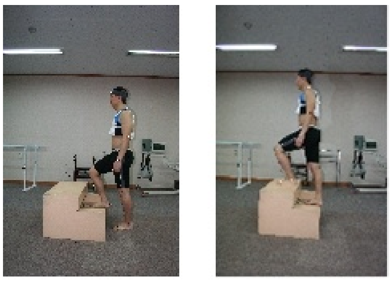
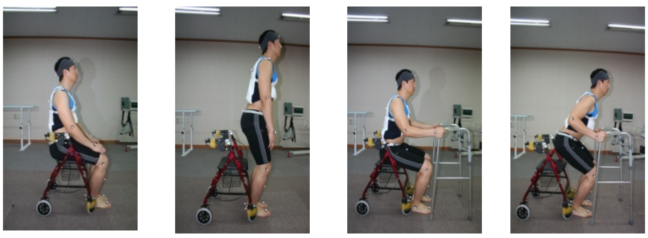


Fig. 2 Stair up for Motion Capture



(a) Without Arm Support (b) With Arm Support

Fig. 3 Two type of Sit-to-stand for Motion Capture

D.2 Sit-to-stand

Fig. 9(a) shows implemented image that position of reflection marker is seen in Fig. 1, and backward kinetic analysis (Inverse Dynamics) was conducted based on this model.

Boundary condition between human body model and chair was applied for sit position according to contact between chair and lower torso and was performed for not affecting from gravity. Also, Boundary condition between human model and walker was applied for stand up with walker by holding walker and human model's hand.

III. RESULT

A. Human model parameter acquisition and verification

Ground reaction force and simulation value getting in normal walk through force plate for human body model verified human body model parameters. Through those values of ground reaction force were obtained as similar based on comparative analysis. (Fig. 10)

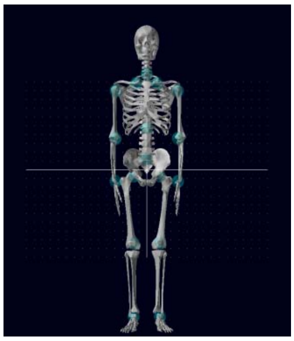


Fig. 4 Skeletal Full Body Model of Human [2]

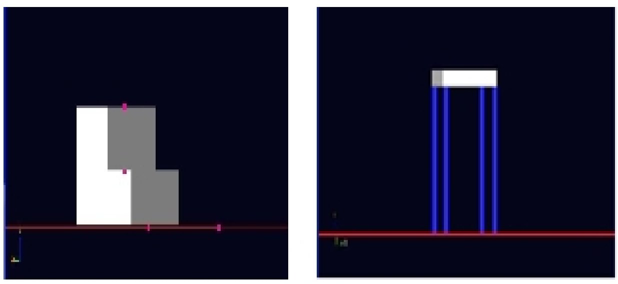


Fig. 5 Stair & Chair Modeling

Also, it was confirmed that the range of difference between analyzing simulation and experimental result by comparison on the basis of existing normal walk shows not much difference. (Fig. 12)

B. Stair up

Performing dynamic analysis of hip and knee joint during stair climbing condition, moment values were obtained from ADAMS. It was observed that maximum torque value of hip joint (1.26Nm/kg) was higher than knee joint (0.49Nm/kg) during stair up stage in sagittal plane. (Fig. 11)

C. Sit-To-Stand

Performing dynamic analysis of hip joint and knee joint during standing with walker and standing with no support condition, moment values were obtained from ADAMS. It was observed that maximum torque value of knee joint (0.72Nm/kg) was higher than hip joint (0.18N,/kg) during sit-to-stand stage using walker. (Table 4)

Also, maximum torque value of knee joint (1.20Nm/kg) was higher than hip joint (0.87Nm/kg) during sit-to-stand stage with no constraints in sagittal plane. (Table 4)

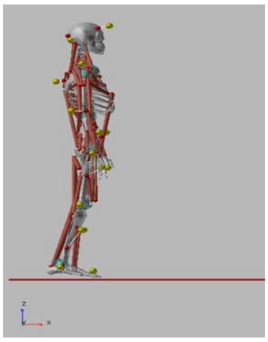


Fig. 6 Reflective Marker Set and Motion Agents

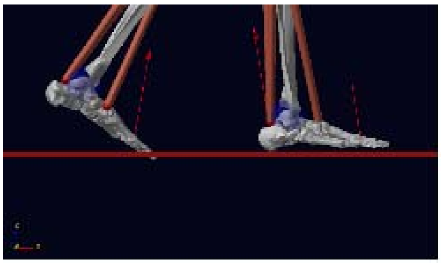


Fig. 7 Contact Force between surface and Human Body Model

Fig. 8 Contact Force between Stairs and Human Body Model

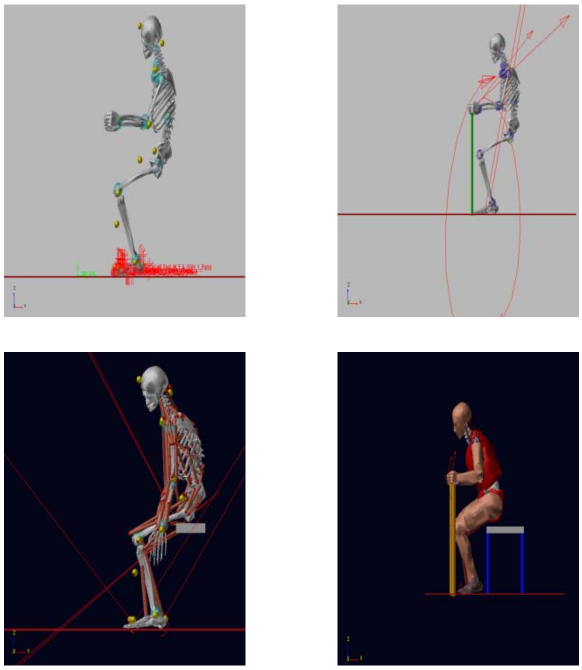


Fig. 9 Sit-To-Stand Simulation

IV. Conclusion

In this study, basic research to obtain biomechanical parameters for optimized design of wearable walking assistant robot was presented and discussed in the condition of its application to the dynamic analysis of gait.

Human model parameters were verified based on gait experiment of normal person and following results were analyzed by comparing with verified human model parameters and test values of lower limb joint due to motion changes.

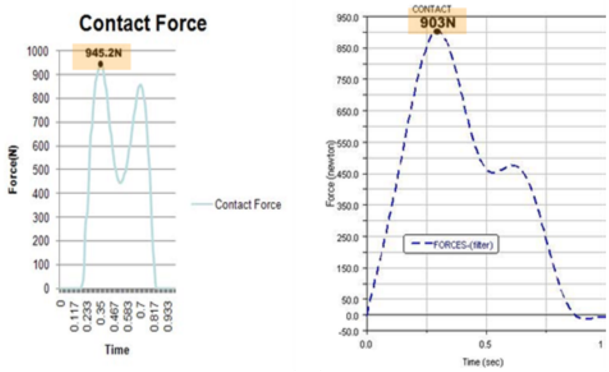


Fig. 10 Contact Force comparison

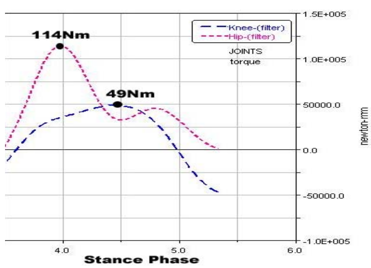
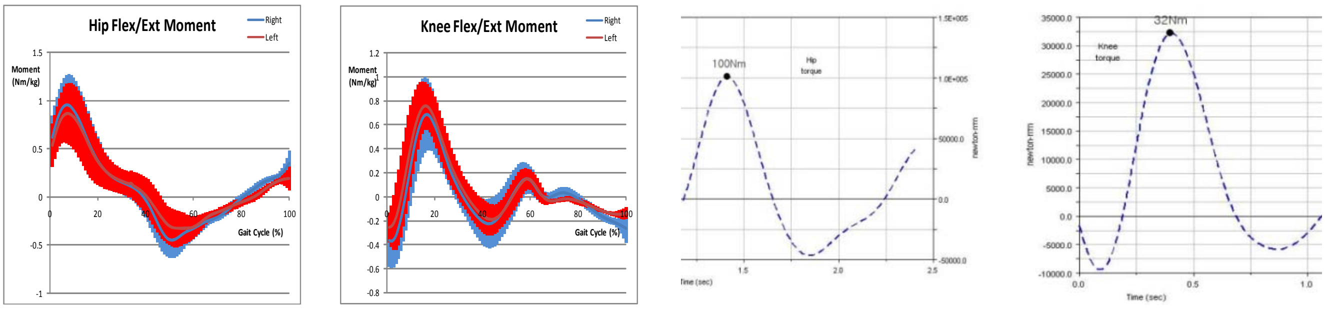


Fig. 11 Result of stair climbing

Table 4 Result of Sit-to-Stand condition

Type	Hip Torque(Nm/kg)	Knee Torque(Nm/kg)
Without Arm Support(S. Nadeau)	0.64	0.88
Without Arm Support(Simulation)	0.87	1.20
With Arm Support (S. Nadeau)	0.53	0.77
With Arm Support(Simulation)	0.18	0.72



(a) Experimental value [3] **(b) Simulation analysis**

Fig. 12 Comparison of experimental value and simulation

The followings are the summary of our simulation results.

1) Previous study have been shown various torque ratio between knee joint and hip joint, and, in this study, it was observed that the torque value in hip joint (114Nm) is higher than twice as much as knee joint(49 Nm). In other words, hip joint needs to stronger forces more than knee joint when it comes to stair climbing condition compared with normal walking condition. [4][5]

2) Torque value in knee joint (100Nm) is higher than hip joint's value (72Nm) approximately 1.3 times and this means that load may concentrate on knee joint as compared with hip joint when it comes to sit-to-stand condition. [6]

V.FUTURE STUDY

In this study, in order to estimate biomechanical parameters, simulation analysis method was used by simplifying stair and chair structures. In the future study, modeling method that can consider multiplex joint motion and standardization of support device such as chair and stairs with more accurate detecting system will be needed to obtain optimized data.

Also, continuous research with more subjects will be needed to analyze characteristics of lower limb joint areas due to change of human motions.

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