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Master's Thesis
석사 학위논문

Kinetic Analysis of Partial Weight Bearing Gait

Choi Wiha (최위하崔 衛 河)

Department of Robotics Engineering

로봇공학전공

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Advisor : Professor Sehoon Oh

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by

Choi Wiha

Department of Robotics Engineering

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A thesis submitted to the faculty of DGIST in partial fulfillment of the requirements for the degree of Master of Science. The study was conducted in accordance with Code of Research Ethics¹

01. 06. 2017

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¹ Declaration of Ethical Conduct in Research: I, as a graduate student of DGIST, hereby declare that I have not committed any acts that may damage the credibility of my research. These include, but are not limited to: falsification, thesis written by someone else, distortion of research findings or plagiarism. I affirm that my thesis contains honest conclusions based on my own careful research under the guidance of my thesis advisor.

Kinetic Analysis of Partial Weight Bearing Gait

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ABSTRACT

Partial Weight Bearing Gait (PWBG) is commonly used method for gait rehabilitation after hip or knee joint surgery. Partial Weight Bearing Gear is emerging gait rehabilitation device for PWBG. By compensating vertical force in gait, a patient can exercise gait with less effort and do exercise of low limb muscle not for maintaining gait ability. However, quantitative research how much weight should be compensated, how much joint force, moment and muscle force weight bearing affects, about change of trajectory change according to weight bearing are not sufficiently especially mobile PWBG on overground not on treadmill. Even though there are quantitative research for PWBG, most of them studied on the treadmill. In this paper, trajectory changes of center of mass, knee and ankle joint, joint force (hip, knee, ankle), joint moment (hip, knee, ankle), ground reaction force using VICON and muscle force (rectus femoris, tibia anterior, gastrocnemius, biceps femoris) using OpenSim as degree of weight bearing changes are presented in wheel type PWBG and suggest various guide line of weight bearing depending on patient situation.

Keywords: Partial weight bearing gait, gait, VICON, OpenSim, joint force, joint moment, ground reaction force, muscle force

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I. INTRODUCTION

1.1 Partial weight bearing gait and previous research

Partial weight bearing gait is commonly used method for gait rehabilitation [16][20]-[22][26]. Partial weight bearing gear(PWBG) is emerging gait rehabilitation device for partial weight bearing gait exercise. By compensating vertical force in gait, an user can exercise with less effort[1][11][19][26]. It helps the user to exercise gait pattern and strengthen muscle related to gait[1]-[3][5][26]. There are many research that shows outstanding rehabilitation results of PWBG[1]-[3][8]-[9][14]. Addition to rehabilitation effect, PWBG decreases the burden to surgery area [5], many therapist and patients prefer to use PWBG[19]. Many advanced PWBG is emerging using novel equipment or robot[7][10][12]-[14][27].However, there is no guideline how much weight bearing is best for a patient, how much force and moment applied to joint as degrees of weight bearing changes: kinetic analysis is needed. Even though many functions are added to new PWBG, kinetic analysis of normal PWBG is not yet studied. That means target performance of novel PWBG is not clear. Many research was studied on the treadmill[4][6][15][17][18][20][27][30]. However, gait in treadmill and on the ground show difference gait pattern to each other[17]-[19][28]-[29].

Therefore, for more effective gait exercise with PWBG, wheel-type or rail-type PWBG is preferred because they can make the user walk more naturally. From that reason, in this study, wheel-type PWBG was used. For kinetic analysis, VICON which is most widely used motion capture system was used for motion capture[31]. For analysis of muscle force OpenSim which is biomechanics simulation was used[32].



Figure1. Wheel type partial weight bearing gait (Shuma DA-2500, Daeam medical Co.,Ltd)

<Figure 1> shows wheel type PWBG used for this study.

1.2 Research contents and goal

In this paper, trajectories of center of mass, knee joint and ankle joint in sagittal and frontal view are analyzed. Maximum joint force and joint moment of hip, knee and ankle in degree of weight bearing also analyzed. And magnitude and trajectory of ground reaction force are analyzed. Lastly, muscle force is analyzed. Joint force is related to burden to joint especially pain that patient feels[20]~[24]. Joint moment is related how much hard patient walks[25][26]. Trajectory is related to assessment of gait pattern[26]~[29]. Ground reaction force is related to gait pattern in view of force generated in walking[30]. Muscle force is related to efficiency of partial weight bearing gait. Using the results of these kinetic analysis, optimized degrees of weight bearing will be found depending on an patient's situation.

II. Theory

2.1. VICON

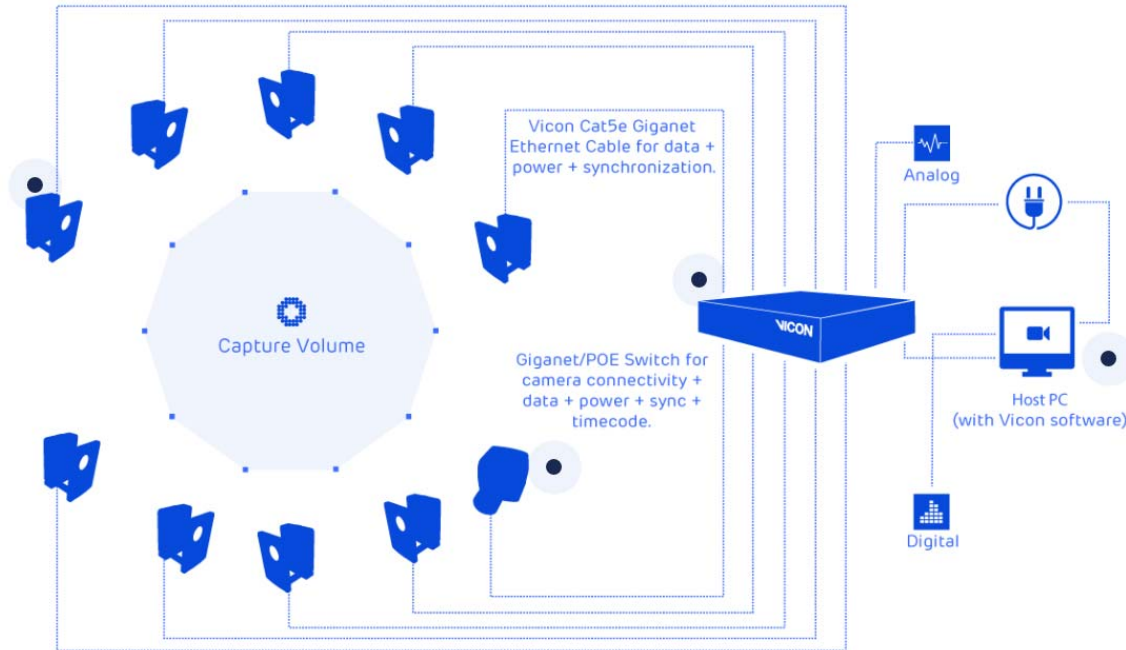


Figure 2. Motion capture system: VICON (VICON Co.,LTD)

VICON is widely used motion capture system [31]. Using marker position data, kinematic data of human body can be calculate as seen <Figure 2>. Furthermore, using force plate data: ground reaction force, kinetic data can be also calculated. In this study, VICON is used for kinetic data of gait in different conditions.

2.2. OpenSim

OpenSim is biomechanics simulator for analyzing human dynamics and muscle force [32] as seen <Figure 3>. Not using EMG sensor, OpenSim can calculate muscle force according to human motion. Moreover, absolute muscle force can be calculated, not relative activation level. In this research, gait 2392 model (23 segment, 92 low limb muscle) which OpenSim

software provides was used. Using marker data, kinetics of the human motion can be calculated. And using computed muscle control, target muscle force, speed, power of the motion can be calculated [33].

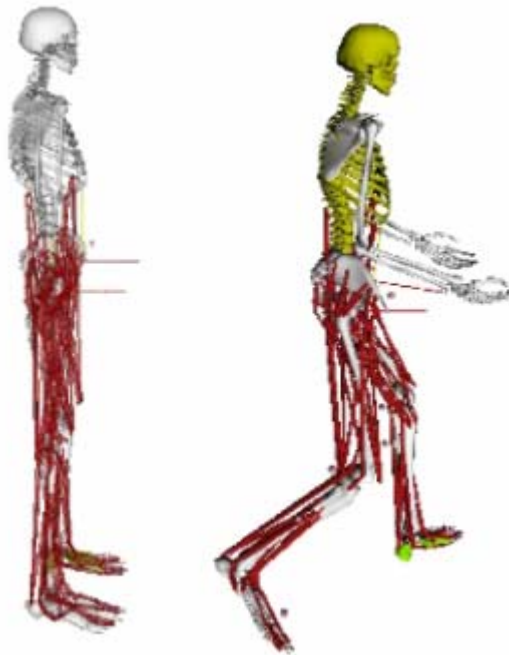


Figure 3. OpenSim

Compared EMG sensor, absolute muscle force can be calculated and no need extra sensor but VICON.

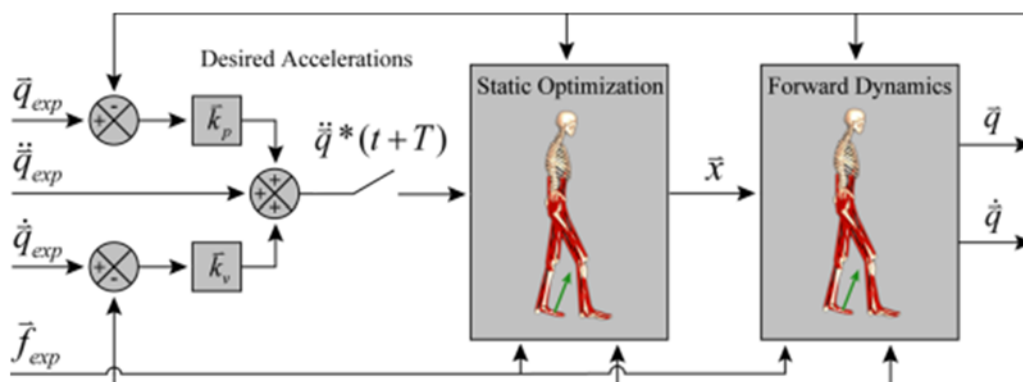


Figure 4. Whole process of OpenSim (simtk-concluce.stanford.edu)

<Figure 4> represents whole process of OpenSim. Computed muscle control reduces times to calculate muscle force and accuracy was validated [33].

$$\ddot{\vec{q}}^*(t + T) = \ddot{\vec{q}}_{\text{exp}}(t + T) + \vec{k}_v \left[\dot{\vec{q}}_{\text{exp}}(t) - \dot{\vec{q}}(t) \right] + \vec{k}_p \left[\vec{q}_{\text{exp}}(t) - \vec{q}(t) \right]$$

Figure 5. Algorithm to calculate desired acceleration (simtk-confluence.stanford.edu)

<Figure 5> represents algorithm of computed muscle control [33]. Using iterative control, desired acceleration, that is, experiment acceleration can be achieved.

III. EXPERIMENTS DESIGN

3.1 Subject

For precise gait posture of gait even though high weight bearing gait is performed, subjects are selected in MMA(Mixed Martial Arts) fighters. 16 subjects(16 males, 0 females, 20~29 ages) are participated in the experiments. Average height is 171.9cm (Standard deviation= ± 3.82 cm), average weight is 72.19kg(Standard deviation= ± 8.93 kg).

3.2 Experiments equipment

In this research, VICON(MX-T10S, 12 EA, Resolution 1120*873, pixel 977760mand frame rate 1000Hz) was used for motion capture. Force plate(OR6-6-2000/AMTI, 2 EA, size 464*508*83mm) is used for measuring ground reaction force. In this research, SHUMA DA-2500 was used as wheel type partial weight bearing gait. For measuring weight precisely, scale of Inbody Co.,Ltd was used.



Figure6. Overall experiment equipment

Table 1. Specification of the mobile partial weight bearing gear

Model name	SHUMA DA-2500
Size	Width 73cm, Depth 85cm, Height 195~215cm
Size of wheel	10.5cm
Weight of the PWBG	24kg
Max weight bearing	100kg

<Table 1> shows specification of the mobile partial weight bearing gear which was used for this study. For removing other effects, handle of the PWBG was removed.

3.3 Experiments protocol

VICON data were collected during 6 trials for each conditions. Subjects walked 2m on the force plate with VICON marker attached in different conditions. Position that VICON markers attached follows Plug-in-gait (low limb) model. Weight conditions were given as random order. Walking speed is not set forth, subjects were ordered to walk as they walked comfortably.

The experiment protocol is as follows.

- 1) Each subject walks 2meters in each weight bearing conditions
- 2) 6 trials are performed in each weight bearing conditions
- 3) Between each trial, 30 seconds rest time is given for reducing effect of fatigue.

IV. EXPERIMENT RESULT

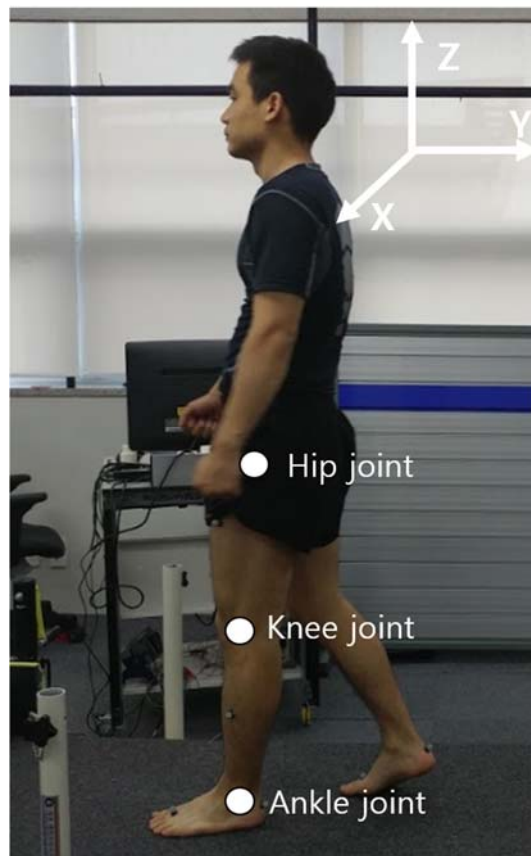


Figure7.Coordinates and target joint

<Figure7> shows position of joint and coordinate axis.

4.1 Trajectory analysis

When a person walks, there are general range of motion (ROM) in center of mass and each knee and ankle joint. Because of harness fixation, center of mass can show gait pattern more intuitive than hip joint movement, trajectory of center of mass is analyzed instead of trajectory of hip joint movement. Therefore, range of motion of each joint can be assessment of gait by comparing ROM among normal gait, 10%, 20%, 30%, 40% and 50% weight bearing gait change tendency of ROM.

4.1.1 Center of mass trajectory

Trajectory of center of mass shows smooth perturbation in normal gait in sagittal plane. Because of such movement, additional force to ground generates addition to weight. In frontal plane, yaw motion generates making eight-shape.

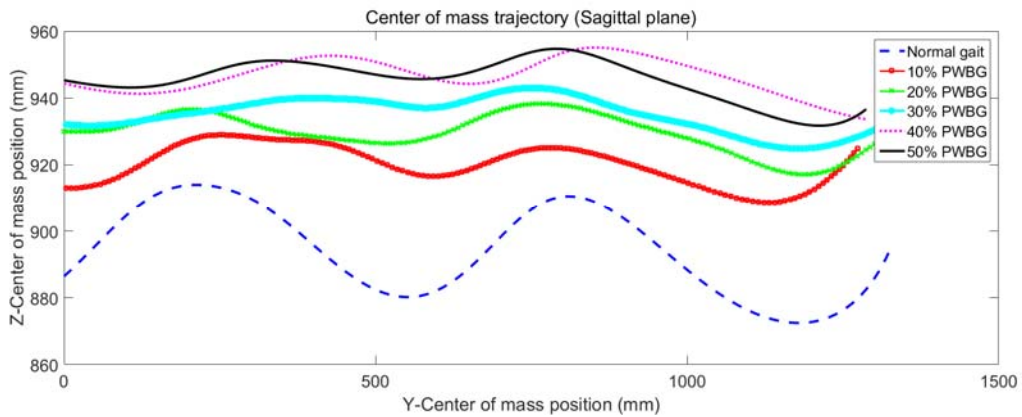


Figure8. Center of mass trajectory (Sagittal plane)

In sagittal plane, as degree of weight bearing increases, overall trajectory of center of mass is shift to up vertically. The more weight bearing increases, the less center of mass perturbs as seen <Figure8>. When PWBG shift the user to up vertically for weight bearing, PWBG restricts the user's vertical movement and affects the perturbation.

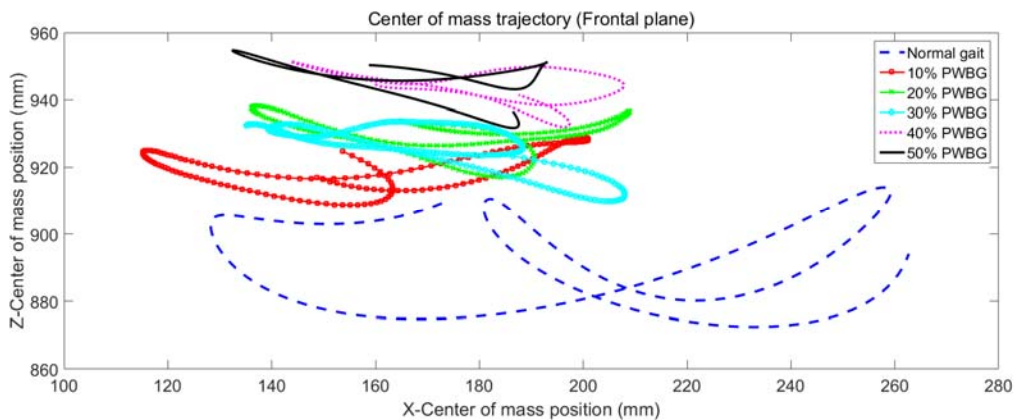


Figure9. Center of mass trajectory (Frontal plane)

In frontal plane, as weight bearing starts, yaw motion is diminished independent to degree of weight bearing because of harness of PWBG fixation as seen <Figure9>. Restriction of yaw motion means that the user feels uncomfortable when the user walks with PWBG. Significant difference between weight bearings is not found. That means restriction of yaw motion is PWBG intrinsic problem not degree of weight bearing problem.

4.1.2 Knee joint trajectory

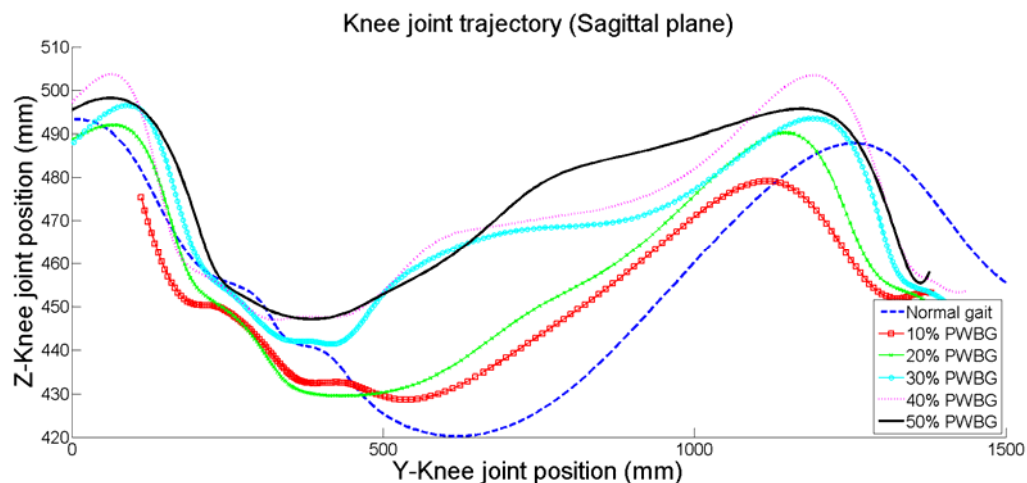


Figure10. Knee joint trajectory (Sagittal plane)

In sagittal plane, vertical displacement of knee joint decreases until mid-stance phase. Descent of knee joint vertically is properly generated when weight bearing starts as seen <Figure10>. The more weight bearing increases, the more minimum displacement of knee joint increases vertically. Because center of mass is shift to up vertically, knee joint also is shift to up vertically in mid-stance phase.

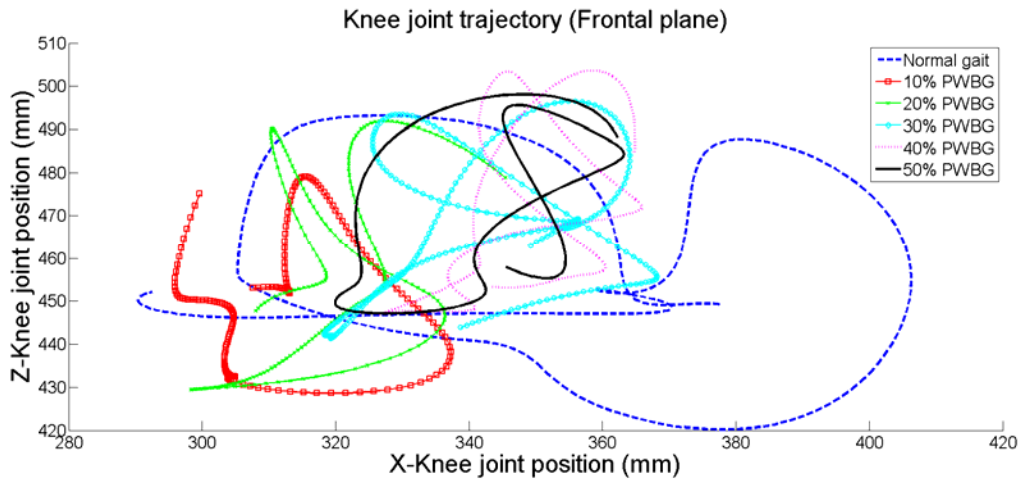


Figure11. Knee joint trajectory (Frontal plane)

In sagittal plane, vertical displacement of knee joint decreases until mid-stance phase. Descent of knee joint vertically is properly generated when weight bearing starts as seen <Figure10>. The more weight bearing increases, the more minimum displacement of knee joint increases vertically. Because center of mass is shift to up vertically, knee joint also is shift to up vertically in mid-stance phase.

In frontal plane, yaw motion of knee joint decreases as weight bearing starts as seen <Figure11>. There are no significant differences between degrees of weight bearing in common with trajectory of center of mass.

4.1.3 Ankle joint trajectory

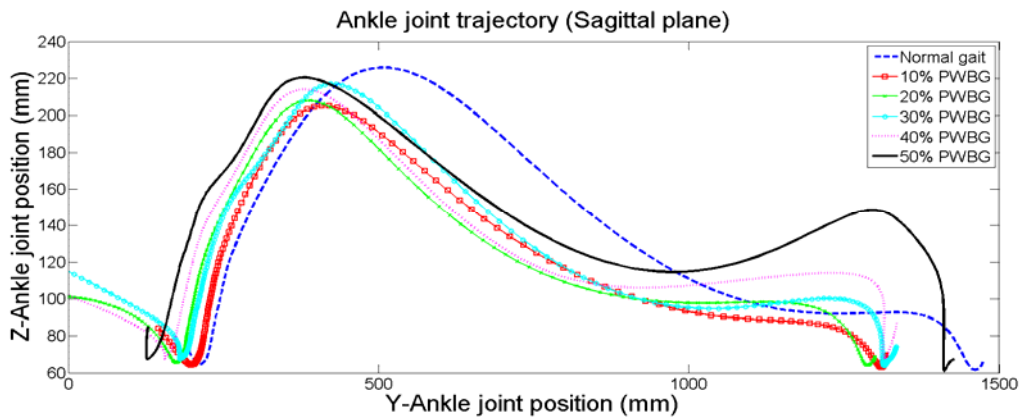


Figure12. Ankle joint trajectory (Sagittal plane)

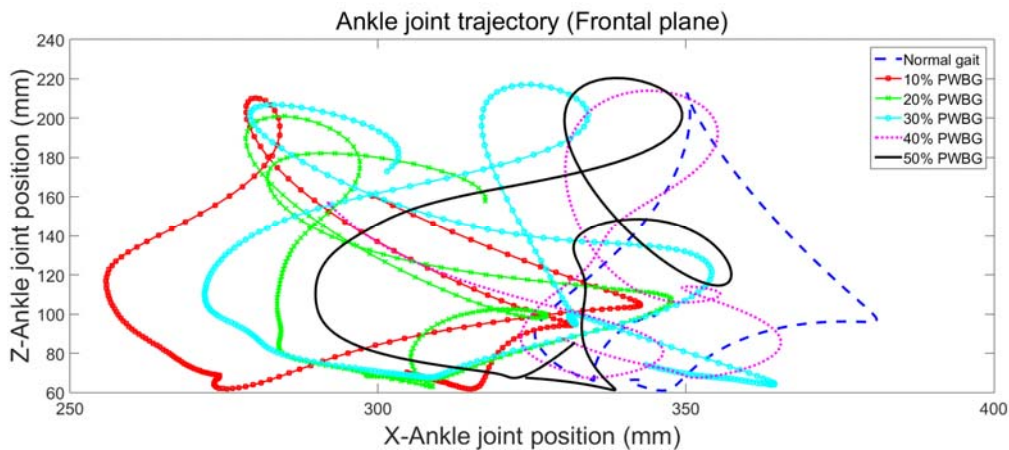


Figure13. Ankle joint trajectory (Frontal plane)

In normal gait, vertical displacement of ankle joint decreases until Mid-stance phase. However, when weight bearing starts, additional peak generates before Heel-strike phase as seen <Figure 12>. It represent modifying attack angle in running represented in SLIP (Spring Loaded Inverted Pendulum) model which is dynamic model of running. That tendency is stronger as weight bearing increases.

In frontal plane, there are no differences between normal and weight bearing even between degrees of weight bearings as seen <Figure13>.

The results show that even though weight bearing has some advantages but there are burden

to ankle joint and yaw motion of ankle is independent to partial weight bearing gear differ from center of mass and knee joint.

4.2 Maximum joint force

To rehabilitate low limb joint surgery patients, how much joint force applied in PWBG is important especially joint implant surgery. Joint force is nominalized by subject's mass because of scaling to find tendency. This research focus on z-axis force as vertical force is dominant in gait. In general large joint force is negative to patient, maximum force data is important to a therapist and a patient. Therefore maximum joint force is analyzed.

4.2.1 Maximum hip joint force

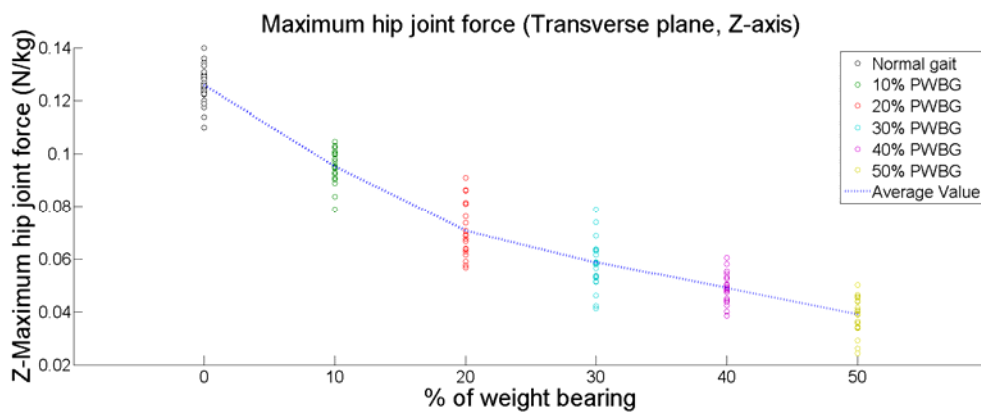


Figure14. Maximum hip joint force

Table 2. Maximum hip joint force

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	0.125 N/kg	0.094 N/kg	0.070 N/kg	0.058N/kg	0.048N/kg	0.039 N/kg
S.D.	0.004 N/kg	0.005 N/kg	0.009 N/kg	0.008 N/kg	0.004 N/kg	0.004 N/kg
p value	0.000	0.000	0.000	0.000	0.000	0.000

<Figure14> shows maximum hip joint force as degree of weight bearing increases. As degree of weight bearing increase, maximum hip joint force decreases. However the descent slope is not always same. When weight bearing is over 20%, descent slope is not stiffer than normal and 10% weight bearing.

In <Table2>, Paired T test was performed. Significant level is 0.05. There is significant difference statistically between degrees of weight bearing.

4.2.2 Maximum knee joint force

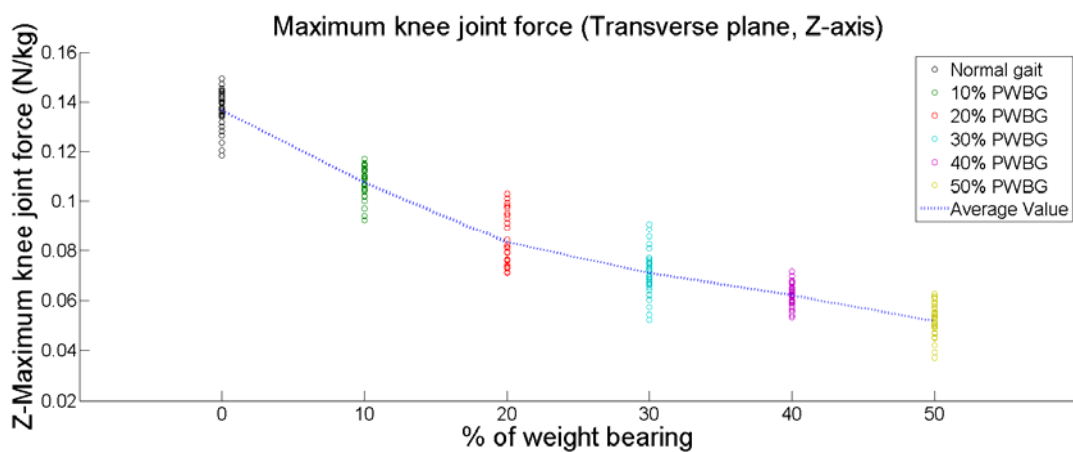


Figure15. Maximum knee joint force

Table 3. Maximum knee joint force

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	0.136 N.kg	0.107 N/kg	0.083 N/kg	0.071 N/kg	0.062 N/kg	0.052 N/kg
S.D.	0.006 N/kg	0.005 N/kg	0.009 N/kg	0.008 N/kg	0.003 N/kg	0.005 N/kg
p value	0.000	0.000	0.000	0.000	0.000	

<Figure 15> shows maximum knee joint force as degree of weight bearing increases. As

degree of weight bearing increase, maximum knee joint force decreases. However the descent slope is not always same. When weight bearing is over 20%, descent slope is not stiffer than normal and 10% weight bearing.

In <Table3>, Paired T test was performed. Significant level is 0.05. There is significant difference statistically between degrees of weight bearing.

4.2.3 Maximum ankle joint force

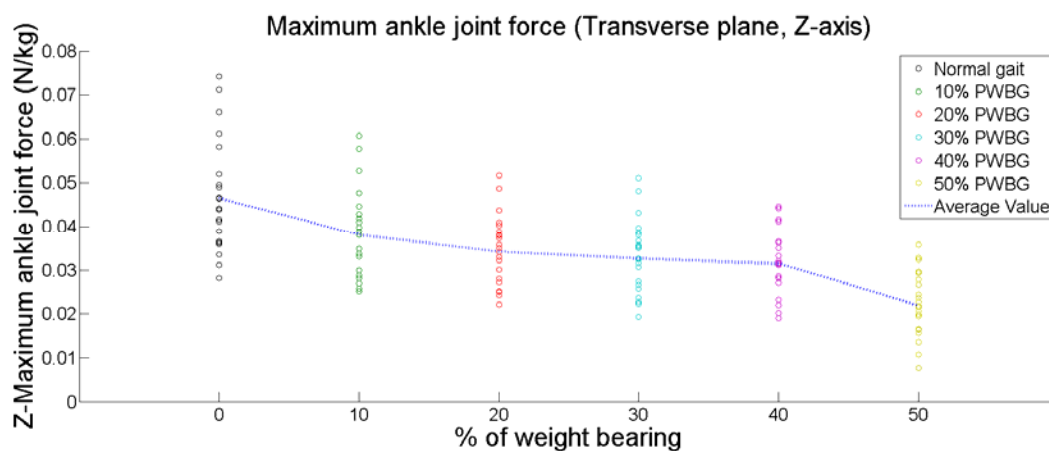


Figure16. Maximum ankle joint force

Table 4. Maximum ankle joint force

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	0.0417 N.kg	0.0346 N/kg	0.0322 N/kg	0.0292 N/kg	0.0277 N/kg	0.0223 N/kg
S.D.	0.0082 N/kg	0.0013 N/kg	0.0013 N/kg	0.002 N/kg	0.001 N/kg	0.004 N/kg
p value	0.000	0.000	0.000	0.000	0.000	0.000

<Figure 16> shows change of maximum ankle joint force as degree of weight bearing increases. As degree of weight bearing increase, maximum ankle joint force decreases.

In <Table4>, Paired T test was performed. Significant level is 0.05. There is significant

difference statistically between degrees of weight bearing.

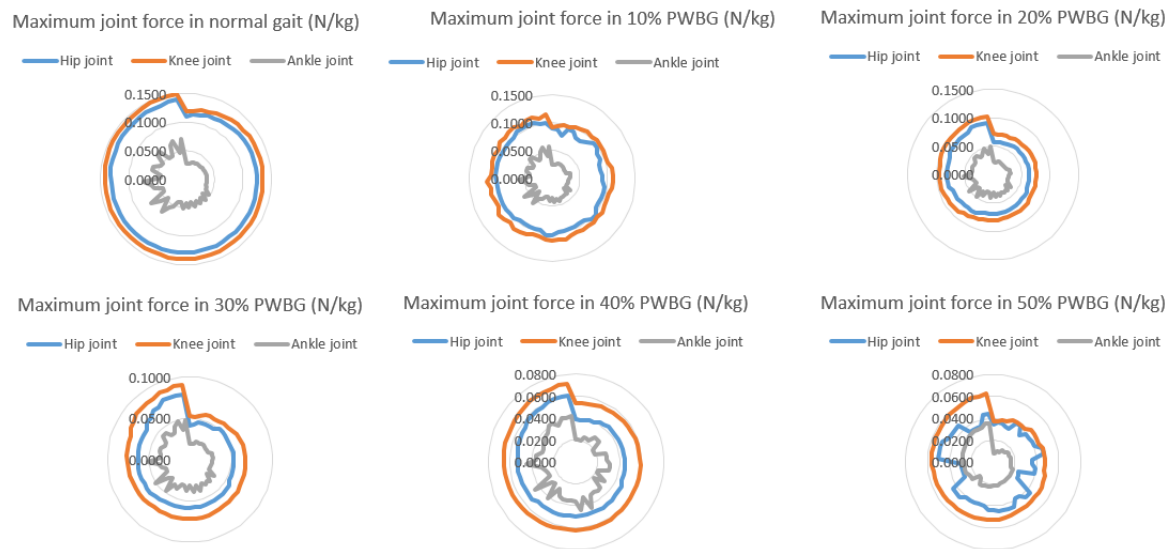


Figure 17. Overall maximum joint analysis

Maximum knee joint force is larger than maximum joint force of hip and ankle as seen

<Figure 17>.Decrease rate is stiffer in hip and knee than ankle.

4.3 Maximum joint moment

Joint moment in sagittal plane means how hard the user feels in gait. Among PWBG users, joint surgery patients occupy high portion, moment to joint is important factor to consider. In this research, sagittal moment is focused on because it's dominant when gait.

4.3.1 .Maximum hip joint moment

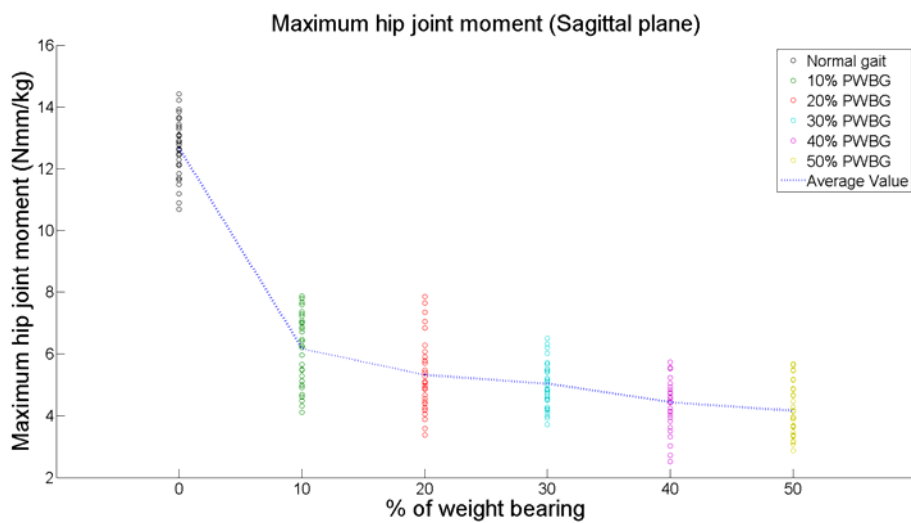


Figure18. Maximum hip joint moment

Table 5. Maximum hip joint moment

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	12.66 Nmm/kg	6.14 Nmm/kg	5.31 Nmm/kg	5.02 Nmm/kg	4.42 Nmm/kg	4.15 Nmm/kg
S.D.	0.88 Nmm/kg	1.08 Nmm/kg	1.10 Nmm/kg	0.66 Nmm/kg	0.76 Nmm/kg	0.73 Nmm/kg
p value	0.000	0.000	0.021	0.000	0.078	

Even though significant difference exists, the effect of weight bearing in moment view as weight bearing starts as seen <Figure 18>. Wheel-type PWBG helps the user walks forward easily. However, in view of moment, there is no need to increases weight bearing more than 20% because effect of moment reduction is not huge in hip joint.

Paired T test was performed as seen <Table 5>. Significant level is 0.05. There is significant difference statistically from normal gait to 40% weight bearing. However, there is no significant difference statically from 40% weight bearing to 50% weight bearing.

4.3.2 Maximum knee joint moment

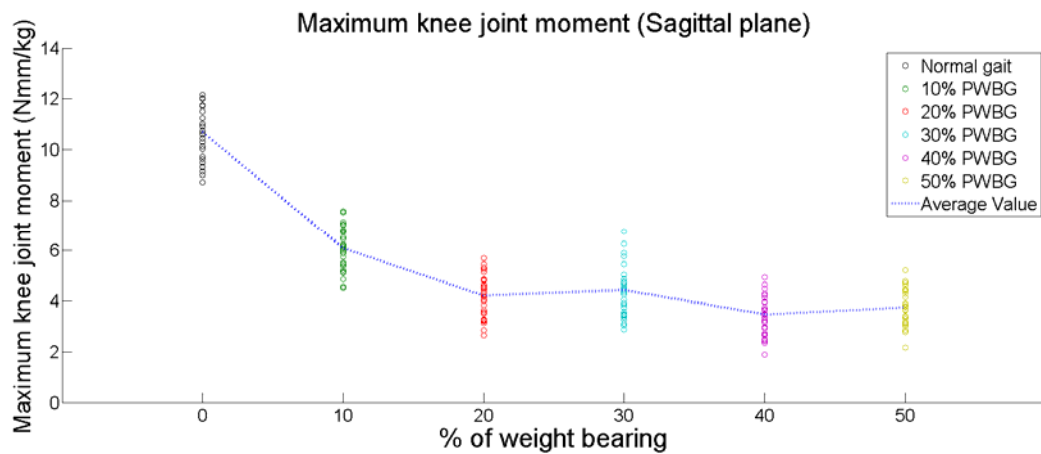


Figure19. Maximum knee joint moment

Table 6. Maximum knee joint moment

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	10.46 Nmm/kg	6.21 Nmm/kg	4.13 Nmm/kg	4.31 Nmm/kg	3.56 Nmm/kg	3.76 Nmm/kg
S.D.	0.09 Nmm/kg	0.06 Nmm/kg	0.04 Nmm/kg	0.08 Nmm/kg	0.04 Nmm/kg	0.01 Nmm/kg
p value	0.000	0.000	0.015	0.000	0.000	0.000

Even though significant difference exists, the effect of weight bearing in moment view as weight bearing starts as seen <Figure 19>. Wheel-type PWBG helps the user walks forward easily. However, in view of moment, there is no need to increases weight bearing more than 20% because effect of moment reduction is not huge in knee joint.

Paired T test was performed as seen <Table 6>. Significant level is 0.05. There is significant

difference statistically from normal gait to 50% weight bearing.

4.3.3 Maximum ankle joint moment

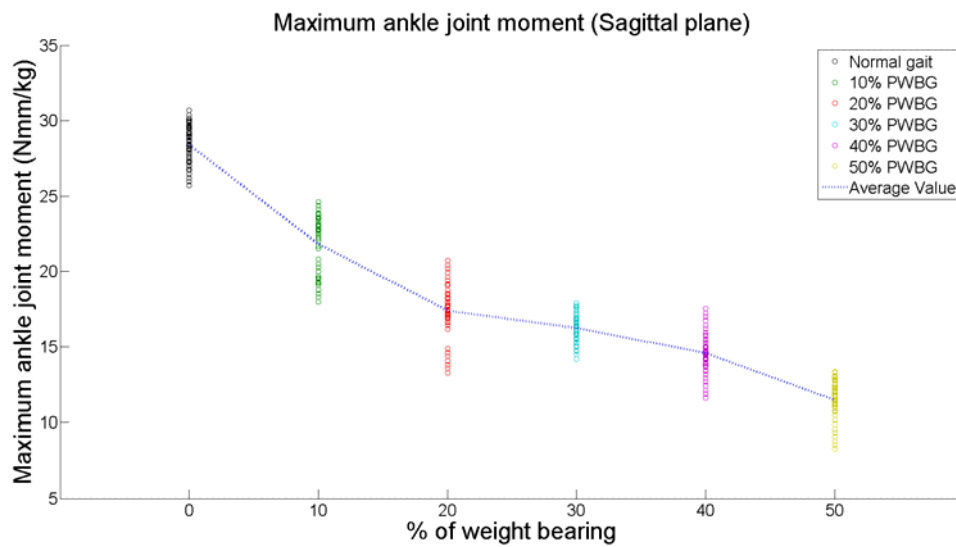


Figure20. Maximum ankle joint moment

Table 7. Maximum ankle joint moment

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	27.24 Nmm/kg	21.31 Nmm/kg	17.36Nmm/kg	15.72Nmm/kg	14.55Nmm/kg	12.13Nmm/kg
S.D.	1.15 Nmm/kg	1.80 Nmm/kg	1.75 Nmm/kg	0.74 Nmm/kg	1.28 Nmm/kg	1.21 Nmm/kg
p value	0.000	0.000	0.000	0.000	0.000	0.000

Even though significant difference exists, the effect of weight bearing in moment view as weight bearing starts as seen <Figure20>. Wheel-type PWBG helps the user walks forward easily. However, in view of moment, there is no need to increases weight bearing more than 20% because effect of moment reduction is not huge in knee joint.

Paired T test was performed as seen <Table 7>. Significant level is 0.05. There is significant

difference statistically from normal gait to 50% weight bearing. The more weight compensated, the less ankle joint moment is needed.

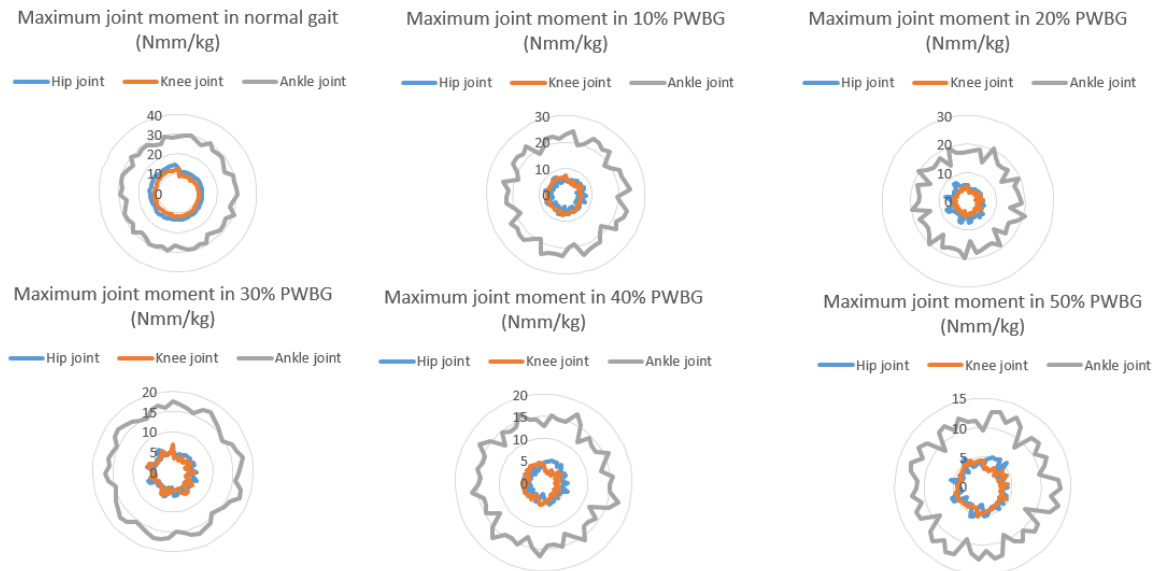


Figure 21. Overall maximum joint moment analysis

Maximum ankle joint moment is larger than maximum moment of hip and knee joint as seen <Figure 21>. Decreasing rate from normal to 10% PWBG is largest.

4.4 Ground reaction force

4.4.1 Magnitude of ground reaction force

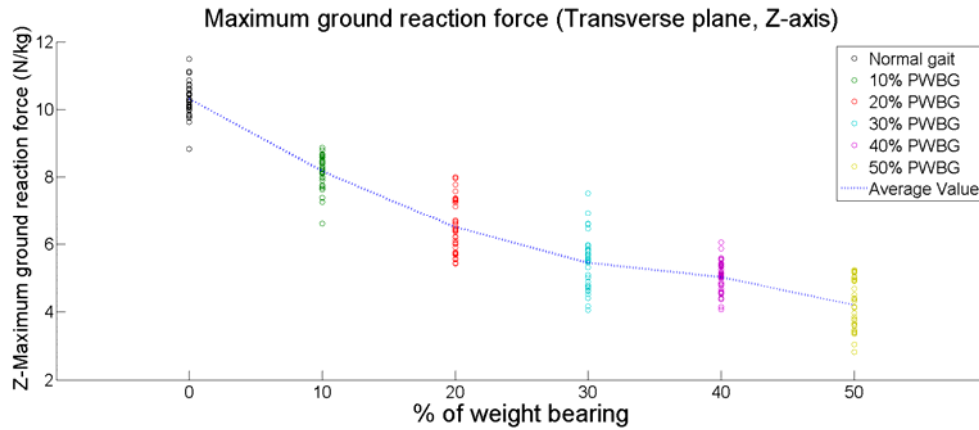


Figure22. Maximum ground reaction force

Table 8. Maximum ground reaction force

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	1.10 N/kg	0.88 N/kg	0.69 N/kg	0.58 N/kg	0.54 N/kg	0.45 N/kg
S.D.	0.010 N/kg	0.009 N/kg	0.0142 N/kg	0.0153 N/kg	0.007 N/kg	0.008 N/kg
p value	0.000	0.000	0.000	0.000	0.000	0.000

As weight bearing increases, maximum ground reaction force decreases as seen <Figure 22>

Descent slope decreases as weight bearing is over 20%.

Paired T test was performed as seen <Table 8>. Significant level is 0.05. There is significant difference statistically from normal gait to 50% weight bearing. The more weight compensated, the less ground reaction force is generated.

4.4.2 Shape of ground reaction force

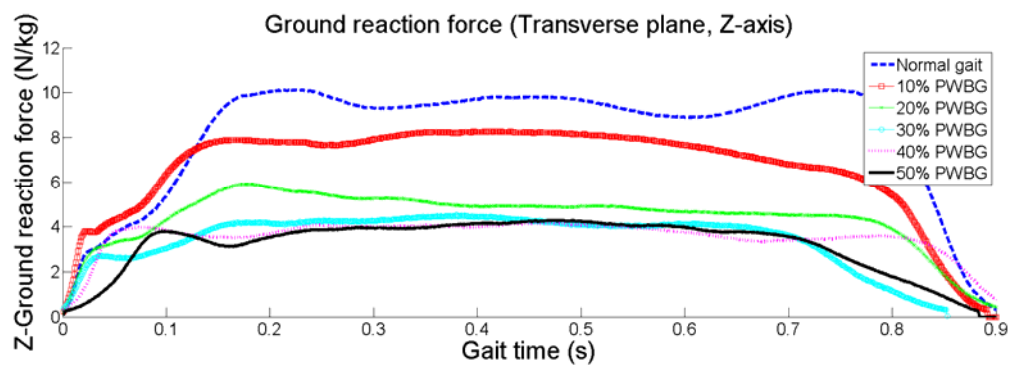


Figure23. Magnitude of ground reaction force

In general, ground reaction force makes two symmetric peaks in toe-off, heel-strike phase.

However, when weight bearing starts, impact peak generates like running as seen <figure 23>.

Two unsymmetrical peaks mean gait with PWBG is similar with running, not walking.

4.5 Muscle force

For analyzing, biomechanics analyzing software “OpenSim” was used which was developed by NIH center at Stanford University.

Target muscles are Rectus femoris, Biceps femoris, Tibia anterior, Gastrocnemius which are closely related to gait.

4.5.1 Rectus femoris

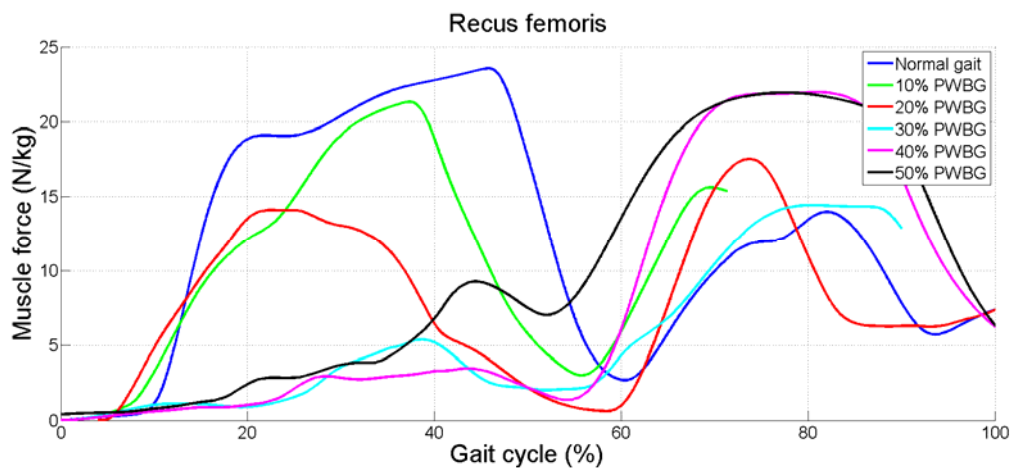


Figure 24. Rectus femoris force

As weight bearing increases, muscle force in Heel-strike, Mid-stance phase decreases. However, muscle force in Swing phase increases. That means, even though burden in vertical force is decreases, for balancing gait posture, additional movement of muscle should be generated. As weight bearing level increases, dominant phase is shift from Heel-strike phase to Swing phase. In view of rectus femoris training, weight bearing level does not make performance of rehabilitation.

Table 9. Maximum Rectus femoris force (N/kg)

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	23.18 N/kg	22.03 N/kg	21.10 N/kg	20.30 N/kg	19.61 N/kg	20.01 N/kg
S.D.	0.60 N/kg	1.28 N/kg	0.94 N/kg	1.18 N/kg	1.93 N/kg	1.56 N/kg
p value	0.008	0.000	0.023	0.157	0.247	

Average value of maximum Rectus femoris force decreases as weight bearing increases. However, there is no significant different in Swing phase when weight bearing is over 30%. Even weight bearing level increases, maximum rectus femoris still maintains similar level. That means exercise effect to Rectus femoris is not diminished.

4.5.2 Biceps femoris long

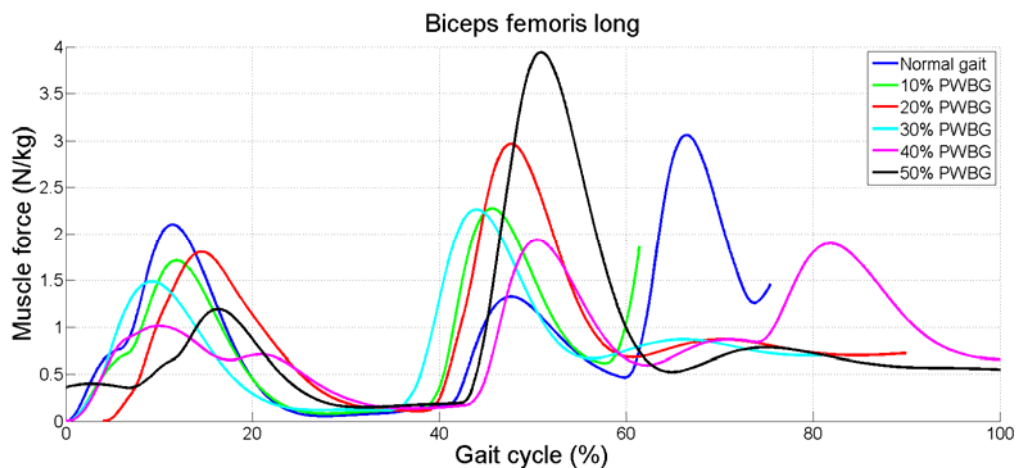


Figure 25. Biceps femoris long force

Biceps femoris long is antagonistic muscle with Rectus femoris and also closely related to gait. As weight bearing increases, muscle force in Heel-strike, Mid-stance phase decreases. However, muscle force in Swing phase increases. That means, even though burden in vertical

force is decreases, for balancing gait posture, additional movement of muscle should be generated similar to Rectus femoris.

In view of Rectus femoris training, weight bearing level does not make performance of rehabilitation.

Table 10. Maximum Biceps femoris long force (N/kg)

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	6.43 N/kg	6.59 N/kg	8.60 N/kg	7.52 N/kg	7.11 N/kg	7.72 N/kg
S.D.	0.40 N/kg	0.49 N/kg	2.55 N/kg	3.31 N/kg	3.98 N/kg	2.88 N/kg
p value	0.522	0.001	0.246	0.696	0.445	

<Table 10> represents maximum value of Biceps femoris long force has no significant different between weight bearing level. Decreasing force in Heel-strike and Mid-stance phase is compensated by increasing force in Swing phase.

In view of Biceps femoris training, weight bearing level does not make performance of rehabilitation.

4.5.3 Tibia anterior

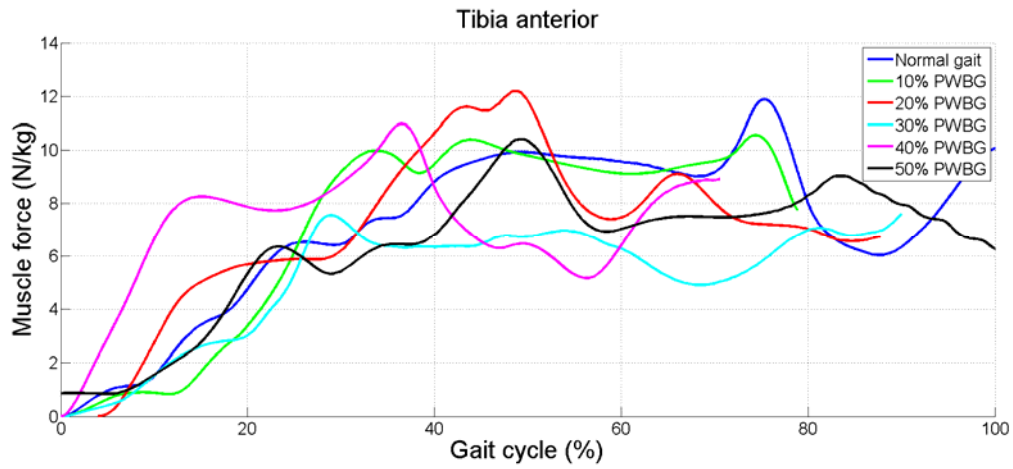


Figure 26. Tibia anterior force

Tibia anterior is related to ankle dorsiflexion and plantar flexion in whole gait phase. Tendency of force of Tibia anterior is not changed according to weight bearing level. Because of ankle dorsi and plantar movement is not related with weight bearing.

Table 11. Maximum Tibia anterior force (N/kg)

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	17.91 N/kg	17.40 N/kg	17.55 N/kg	12.78 N/kg	13.00 N/kg	14.50 N/kg
S.D.	1.23 N/kg	1.42 N/kg	0.17 N/kg	0.66 N/kg	0.57 N/kg	0.34 N/kg
p value	0.173	0.605	0.000	0.830	0.051	

<Table 11> represents average value of maximum force of Tibia anterior is not significantly different as weight bearing increases. Therefore, PWBG is not effective to exercise Tibia anterior.

4.5.4 Gastrocnemius medialis

Gastrocnemius medialis is related to Toe-off phase in gait.

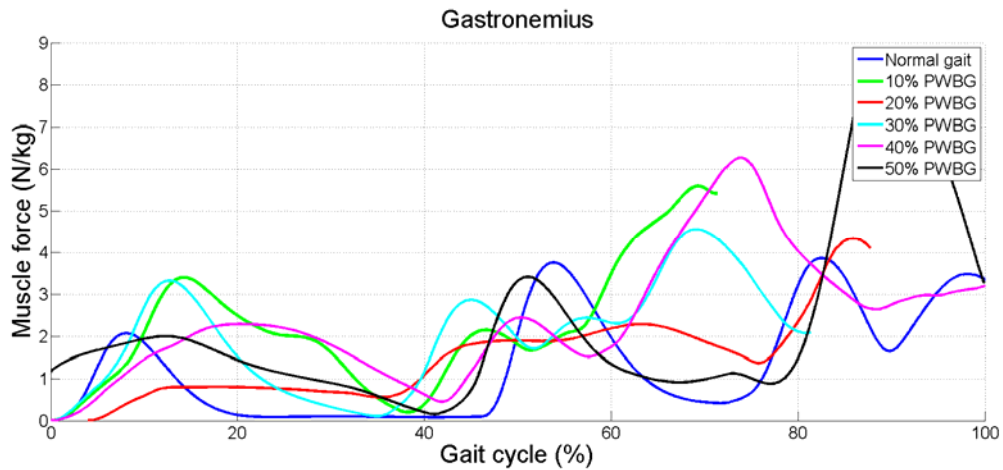


Figure 27. Gastrocnemius medialis force

Because of weight bearing, Gastrocnemius medialis is related to Toe-off phase in gait. As weight bearing increases, muscle force increases in Toe-off phase. In unstable posture, to walk forward, Gastrocnemius medialis generates more force as weight bearing increases.

Table 12. Maximum Gastrocnemius medialis force (N/kg)

	Normal gait	10% PWBG	20% PWBG	30% PWBG	40% PWBG	50% PWBG
Mean	7.52 N/kg	9.76 N/kg	10.08 N/kg	7.21 N/kg	9.14 N/kg	9.81 N/kg
S.D.	1.52 N/kg	2.32 N/kg	0.85 N/kg	2.01 N/kg	4.34 N/kg	4.26 N/kg
p value	0.000	0.876	0.001	0.005	0.468	

<Table 12> represents average value of maximum Gastrocnemius force increases.

As weight bearing increases, an effect of exercise of Gastrocnemius medialis increases.

V. Conclusion

In this experiment, we investigate the tendency of change with degree of weight bearing. In general, weight bearing over 20% makes the user walk abnormally. Even though joint force is reduced as degree of weight bearing increases, there is no significant effect to joint moment. To consider gait trajectory, for more effective gait exercise, 10%~20% weight bearing is suitable to general patients. Moreover, 30% over weight bearing increases ROM of ankle, there is possibility to make bad effect to ankle joint. When considered pain and discomfort of gait, increasing weight bearing is not always good for patient. When investigates ground reaction force and ankle trajectory, gait with PWBG is similar to running pattern not gait pattern. Novel PWBG that maintain normal gait not running and keep advantage of current weight bearing is next step.

In view of muscle force, maximum force of Biceps femoris, Gastrocnemius medialis decreases as weight bearing increases. In contrast maximum force of Rectus femoris, Tibia anterior increases as weight bearing increases. Even though weight bearing reduce muscle force in Heel-strike phase, for compensating unstable gait posture, more muscle force generates as weight bearing increases. In view of muscle training, weight bearing level is not important.

VI. Appendix

1. Harness modification



Figure28. Trango harness

When weight bearing with harness, all force weight bearing applied to inguinal region (red circle in <Figure29>) and make huge pain to the user. Therefore to reduce pain to the user, attach cushions to the inguinal region of harness as seen <Figure29>.



Figure29. Harness modification

2. Caution for PWBG assessment using Vicon

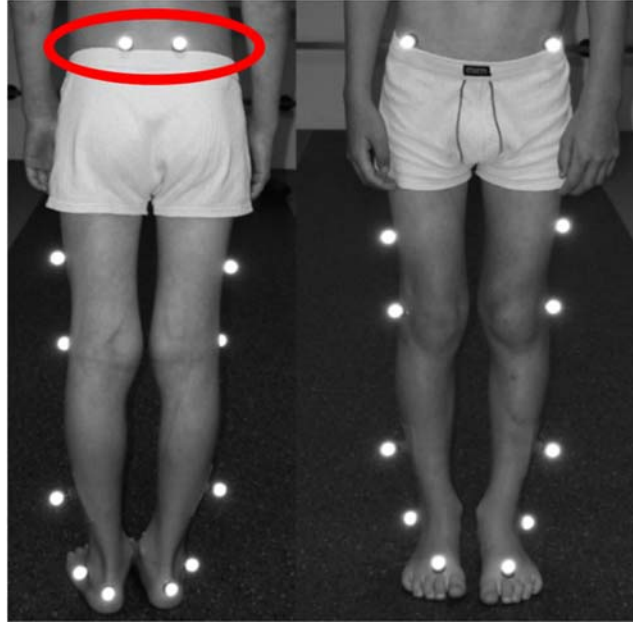


Figure30. Plug in gait marker set

Even though the harness used in this study is modified to represent marker to VICON camera, especially marker in PSIS position (red circle in <Figure30>) is lost by VICON camera. For balancing, harness must cover the user's back. Markers of PSIS, ASIS is decisive to kinetic analysis of VICON, those region should be considered. In this study, the problem is solved by harness modification.

For precise force data, wheel should not step force plate. Therefore for this study, width of PWBG is wider than force plate width.

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요약문

부분체중부하보행(Partial weight bearing gait)의 운동학적 분석

부분 체중 부하 보행은 보행 시 수직방향의 힘을 감소시켜줌으로 수술 후 환자나 보행이 어려운 사람들의 보행 재활을 돕는다. 보행패턴을익히고관련근육을강화시킨다는점에서그효과가많은연구를통해증명되고있지만정성적인분석만이루어져있지운동학적으로정량적인분석이많이이루어지지않아 재활에서기준이되는데이터가없다. 이 논문에서 가장 적합한 무게 보상 정도와 무게 보상 정도에 따른 각 관절에 미치는 힘과 모멘트, 지면반력, 근육의 힘에 대한 정량적인 분석을 운동학적 관점에서 실시하였다. 관측대상은 무게중심, 고관절, 무릎관절, 발목 관절이고 관측근육은 대퇴직근, 대퇴이두근, 전경골근, 비복근이다.

총 16명의 성인 남성을 대상으로 실험을 실시하였으며 일반 보행, 10% 무게보상, 20% 무게보상, 30% 무게보상, 40% 무게보상, 50% 무게보상을 한 상태에서 보행을 하였고 VICON을이용해운동학적변화를관찰하였고OpenSim을이용하여근육힘을계산하였다. 무게 중심의 궤적은 수직 방향으로 편심(drift)가 존재한다. 무게 보상으로 인해 수직방향으로 몸이 들리기 때문이다. 이 과정에서 보행시 발생하는 수직 방향의 진동(perturbation)이 감소하는 경향을 보였다. 이를 보상하기 위해 무릎관절이 Mid-stance 과정에서 일반 보행에 비해 수직 방향으로 상승하는 경향이 무게 보상 정도가 커질수록 증가하는 경향을 보였다. 발목관절은 Heel-strike 직전에 무게 보상을 하면 추가적인 peak를생성하게된다. 무게 중심과 무릎 관절의 경우 하네스와 무게 보상으로 인한 구속으로 좌우 움직임이 일반 보행에 비해 현격히 줄어 들게 되어 비정상적인 보행을 하게 된다. 발목 관절은 하네스의 구속으로 인한 좌우움직임 제한이 나타나지 않았다. 지면 반력의 형태 역시 변화하였다. Toe-off와 Heel-strike 부분의 공평한 분배 모습을 보이는 일반 보행과 달리 무게 보상이 진행될수록 Heel-strike로인한지면반력이보이는, 달리기와 유사한 지면 반력 특성을 보였다. 각 관절에 작용하는 모멘트는 일반보행과 비교해 무게보상이 이루어짐에 따라 크게 감소하였고 20% 이상 무게보상이 이루어지면 무게 보상 정도 사이에서는 큰 차이가 없었다.

대퇴직근은 무게보상이 증가함에 따라 Heel-strike 과정에서 힘이 감소하였고, Swing 과정에서 힘이 증가하였다. 대퇴이두근은 대퇴직근과 유사한 경향성을 보였다. 전경골근의 경우는 무게 보상 정도에 따라 큰 차이를 보이지 않았고 무게보상이 증가함에 따라 발생하는 힘이 약간 감소함을 보였다. 비복근의 경우는 Toe-off 과정에서 무게 보상이 증가함에 따라 발생시키는 힘이 더 증가함을 보였다. 발생시키는 근육 단련 측면에서 무게 보상 정도를 바꾸는 것은 큰 차이를 보이지 않았다.

핵심어: 부분체중부하보행, VICON, 운동학,관절,모멘트,지면반력,운동궤적, 근육힘, OpenSim

