The Study of Joint Displacement by the Impact to Lower Limbs due to Gait Feature

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Abstract

Previous research regarding walking analysis focus on walking speed and ground reaction force classified by age. Research of change of walking type regarding ages, analysis of walking features of adult men and grown men due to ages, biomechanical analysis of walking period of obese children (male), and analysis of walking of Korean adults using 3 dimensional motion measurements. Most of the research in walking analysis is limited to ground reaction force and joint angle analysis by 3D motion analysis. Our study focuses on each joint linear displacement and impact forces according to walking speed, feature and gender using three dimensional motion and acceleration measurements. Three walking speeds, that walking, power walking and running, are defined by checking walking speed of each volunteer in pre-experiments. Four reference points, are the tip of toe, malleolus, patella and hip joint, were selected for measuring joint displacements in 3-dimensional motion analysis. The factors affected by impact forces were defined as A (walking speed), B (body segment), C (gait features), and D (axis). Joint linear displacements on the knee on the y axis also were higher than for any other body parts regardless of walking speed. In addition, the relationship of the impact forces to other experimental factors was also analyzed.

Keywords: Joint Linear Displacement, Impact Force, Motion Analysis, Gait Feature,
functional insoles and use shock absorbing outsoles (2, 13), and use the newly developed materials (12). Body impact forces are evident in walking, jumping and running motions. For relief of the impact force, it is necessary to apply proper attitudes, like reducing joint angles. Using a shock absorbing material on the heel is also a relief to the impact force (8). As mentioned in previous research, impact forces are related to the speed of the walking feature. While walking and running, the speed leads to an increase in impact force and pressure on the foot. Most of problems, while walking, occur at the stance phase, when body receives an increase in the weight load because of stance phase. Then, biomechanical research about walking speeds and features have been performed. Previous research regarding walking analysis are walking speed and ground reaction force classified by age (10), researches of change of walking type regarding ages (4), analysis of walking features of adult men and growth men due to ages (5, 7), biomechanical analysis of walking period of obese children (male) (9), and analysis of walking of Korean adults using 3 dimensional motion measurement (6). So far, most of research in walking analysis is limited to ground reaction force and joint angle analysis by 3D motion analysis. Our study focuses on each joint displacement and impact forces according to walking speed, feature and gender using three dimensional motion and acceleration measurements.

II. Measurement and analysis of Lower joint displacement and impact forces due to walking speed

Six healthy young men and eight women (20’s) who had not experienced any musculoskeletal diseases and injuries and no morphological deformations on foot volunteered for the study. The mean age of men was 26.57 years and the mean age of women was 23.25 years. The average height of men was 175.14 cm and the average leg length was 97.71 cm. Women subjects had an average height of 161.75 cm and an average leg length of 88.25 cm. Experiments were run at three walking speeds for each gender on treadmill. The three walking speeds were walking (W), power walking (PW) and running (R). They are defined by checking walking speed of each volunteer in pre-experiments. For men, W is 5 Km, PW and R are 7.5 and 9 Km. For women, W is 4 Km, PW and R are 5.5 and 7 Km. For maintaining a stable experimental condition, each volunteer was fully trained to adjust to speed changes.

Acceleration and three dimensional motions were simultaneously measured and runs were repeated 5 times for 5 seconds. The measurement positions were the calcaneus of the ankle, the most prominent part of the patella, and the end point of the femur connecting to the ilium. Four reference points, the tip of toe (R1), malleolus (R2), patella (R3) and hip joint (R4), were selected for measuring joint displacements in 3 dimensional motion analysis (Fig 1). The factors affected by impact forces were defined as A (walking speed), B (body segment), C (gait features), and D (axis). These results are shown in Table 1. The accelerometer (Mega Electronics) was attached to the skin with paper tape and then overlaid with compressor bandage. Attachment points were also marked on the skin surface for a replication of the measurement position. The maker for motion analysis was attached to four reference points (R1, R2, R3 and R4) with paper tape. Before the experiment, Calibration was performed for 3 seconds for setting up spatial coordination. Three dimensional acceleration measurement equipment (Mega Electronics) was used. Three-axis accelerometer can measure impact forces in 3 dimensional variations (anterior-posterior, longitudinal and left and right). The data were analyzed by ME-6000T8 system. A 3 dimensional motion analyzer (The Ariel Performance Analysis System (APAS 2000)) can measure the displacement of a joint with speed of 60 frames per second (Fig 1).
2-1. 3-Dimensional acceleration analysis of lower limb joints

Impact forces increase with increasing walking speeds. According to Lee, C.M. et al. (2001), the change from walking to power walking is higher (by 34%) than that from power walking to running. Impact forces were significantly higher in the lower limbs than in the upper limbs. The impact forces were highest on the ankle, followed by the knee, and then the thigh. The fact that impact forces decrease as they move up to higher body segments has been confirmed by several researchers (3, 6). The impact forces vary in proportion to body weight when comparing the groups. The impact force at the heel strike is higher than that at the toe. Those trends are found both in men and in women, but there wasn’t a significant difference. In comparing axis, impact forces in the Z axis (vertical movement) showed the highest value among three axis. In addition to the main effects for walking speed, body segments, weight, gait stages, and axis, interaction effects were also examined. Impact forces were significantly ($p < 0.001$) higher at the lower limbs than at the upper limbs. However, impact forces at the knee were higher than that at the ankle in the Y axis even though the knee position is higher than the ankle position. This phenomenon is shown in all speeds, walking feature and gender. The impact force on the knee was higher than that on the ankle for Y axis regardless of walking speed.

<table>
<thead>
<tr>
<th>List</th>
<th>Factor</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Walking Speed(km/hr)</td>
<td>5</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>AnkleKneeThigh</td>
<td>9</td>
<td>5.5</td>
</tr>
<tr>
<td>B</td>
<td>Body Segment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AnkleKneeThigh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Gait Feature</td>
<td>HS</td>
<td>TO</td>
</tr>
<tr>
<td></td>
<td>AnkleKneeThigh</td>
<td></td>
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<tr>
<td>D</td>
<td>Axis</td>
<td>X</td>
<td>Y</td>
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have focused on normal walking for elderly people, obesity and lower limb disease subjects. However, most of the research is limited to analyzing joint angle of the ankle and ground reaction force. Therefore, the focus of this research is to analyze variations range (VR) of joint displacement of the ankle, knee and hip joint in 3 axes by 3 D motion analysis. Joint Linear Displacement (JLD) of 3D VR were highest on the ankle, followed by the knee, and then hip joint like the results of Kim’s study (17) that investigate variations of joint angle of the ankle, knee and hip joint. In individual analysis of 3-axis, results show that joint linear displacement of 3D VR were highest on the ankle, followed by the knee, and then hip joint in Longitudinal and Anterior-Posterior axes. However, JLD of 3D VR was the highest on the knee, followed by the hip joint, and then ankle in Left and Right axis. Moreover also, the result shows significant effects ($p$-value $<0.01$) on 99% confidence interval.

III. Correlation between impact forces and VR of joint linear displacement on the lower joint.

There is a low correlation between walking speed and VR of joint linear displacement, but a correlation between impact forces and walking speed. Impact forces shows a decreasing tendency when joint is crossing to CBM, the same effect is shown in VR of joint linear displacement. VR of joint linear displacement were highest on the ankle, followed by the knee, and then hip joint. The larger impact forces lead to the bigger VR of joint linear displacement. Figure 3 shows a correlation between impact forces and VR of knee joint linear displacement in power walking ($r^2 = 24.5\%$, $P < 0.01$). However, another result is shown in left-right axis. In left-right axis, results show that impact forces were the highest on knee,
followed by the ankle and then hip joint. On the other hand, VR of joint linear displacement were the highest on knee, followed by hip joint, and then ankle. The knee shows the largest impact forces in left-right axis, and same tendency is shown on VR of joint linear displacement. However, the ankle shows smaller VR of joint linear displacement than that of hip joint, even though the ankle has a larger impact force than that of hip joint. This phenomenon comes from the reason why VR of ankle joint linear displacement are limited coercively when foot touched ground while heel striking. Therefore, high impact forces on the ankle occurred in left-right axis are dispersed to the knee and hip joint. This phenomenon also increases VR of knee joint linear displacement. For the future study, experiments at various levels of speed, (e.g. running) are necessary to know more detail of correlation between impact forces and VR of joint linear displacement.

Reference

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