

IMPACT LOADING IN OSTEOARTHRITIC WOMEN DURING VARIED WALKING CONDITIONS

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ABSTRACT

Background: Although osteoarthritis affects a great portion of the population little is known on the loading of the human locomotor system of osteoarthritics during ambulation.

Purpose: To examine and compare the characteristics of shock generation and absorption between healthy and osteoarthritic females during various walking conditions.

Material and Method: Ten middle-aged healthy and ten osteoarthritic women walked barefoot on a motorized treadmill at 1.5 and 2.5 miles per hour while its surface was level, uphill and downhill. The peak decelerations of the shank and head during the contact of the foot with the ground were recorded with a low mass accelerometer. In order to secure unbiased estimation of the results, ten steps were computed for each walking condition in all subjects. A three-way ANOVA compared all dependent variables.

Results: Similar peak shank deceleration was recorded between healthy (2.83 ± 0.19 g) and osteoarthritic women (2.78 ± 0.23 g) ($p>0.05$) whereas osteoarthritic displayed significant ($p<0.05$) lower values of peak head deceleration (0.66 ± 0.05 g) than healthy females (0.81 ± 0.06 g). Fast walking produced significantly higher deceleration values ($p<0.01$) than slow walking at the shank (3.71 ± 0.23 g vs. 1.91 ± 0.31 g) and head (0.97 ± 0.07 g vs. 0.51 ± 0.07 g). Significant peak tibial (2.46 ± 0.42 g) ($p<0.05$) and head deceleration (0.78 ± 0.12 g) ($p<0.01$) values were also found during level walking. During uphill ambulation, there were also significant peak tibial (3.15 ± 0.57 g) ($p<0.05$) and head deceleration (0.62 ± 0.09 g) ($p<0.01$) values. Lastly in downhill walking, there were significant peak tibial (2.81 ± 0.39 g) ($p<0.05$) and head deceleration (0.81 ± 0.13 g) ($p<0.01$) values.

Conclusion: The findings might suggest that slow and level walking could be recommended to patients suffering from osteoarthritis since they produce the least stress on the musculoskeletal system.

Keywords: Osteoarthritis · Walking · Accelerometer · Shock Attenuation · Impact Loading

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INTRODUCTION

Osteoarthritis is the most prevalent type of rheumatic diseases affecting 21 million Americans¹. Osteoarthritis is chronic and involves mostly weight bearing joints such as hips, knees, feet and spine. Specifically, the cartilage of joints degenerates and inflammation may develop in all periarticular and intra-articular tissues. Finally, degeneration develops in joint capsules, tendons, ligaments, fasciae and muscles. Frequently, limitation of various movements occurs, which, in turn, causes weakness of muscles, development of contractures and distortion of correct posture²⁻⁵.

Despite the efforts of medical sciences, there is no known cure of osteoarthritis. Today, the treatment includes the use of assistive devices to protect the afflicted joints, weight control, medication, surgery, application of heat or cold over the painful joints and exercises. The goal is to decrease pain and maintain functional activities by preserving or improving strength and muscular endurance⁶⁻¹².

Recently, progressive physicians recommend exercise programs for osteoarthritic patients^{13,14}. Exercise booklets have been prepared by the Arthritis Foundation, providing instruction for active range of motion of different joints. Although these exercises maintain mobility of joints, they improve muscular strength and endurance only minimally^{15,16}. In addition, they fail to promote functional activities, tend to become boring and as a result, they are often abandoned. Perhaps, exercise activities such as slow or fast walking could enrich a therapeutic program, promote functional ability and improve cardiovascular benefits in osteoarthritic patients. However, there is scarce research upon which to base recommendations for involvement in programs of therapeutic walking^{17,18}. Little is known about the effects of such factors as variation in walking speed and terrain on osteoarthritis. It is conceivable that these factors may influence the levels of musculoskeletal loading, and, thus, further accelerate the

progress of the disease. Therefore, the purpose of this study was to investigate the levels of loading in healthy and osteoarthritic women during various conditions of walking.

MATERIAL AND METHOD

Subjects

Two groups, each consisting of ten subjects, were chosen for this investigation. One group was comprised of individuals who were healthy, and the other was consisted of those with documented osteoarthritis of the lower extremities and/or spine. All participants were volunteers, middle-aged females of average height and weight (Table 1), referred by local rheumatologists, or recruited from exercise classes at the University of Toledo, South Toledo YMCA, St. Vincent's Hospital and Flower Hospital. A frequency distribution of the affected joints in the osteoarthritic individuals is reported in Table 2

Table 1. Means and standard deviations of the anthropometric characteristics of all subjects

	Healthy (N=10)	Osteoarthritic (N=10)
Age (years)	60.60 ± 5.72	56.60 ± 5.25
Weight (Kgrs*)	66.93 ± 8.07	73.38 ± 11.91
Height (meters)	1.62 ± 0.06	1.63 ± 0.04

Each individual was screened through the use of a questionnaire to exclude any diagnosed cardiovascular, neurological or acute orthopaedic conditions that might have affected her gait. A typewritten handout was delivered to each subject explaining the procedure, as well as the risks and benefits resulting from the study. An informed consent section was included in the handout that each participant signed prior to testing. The study was approved by the Human Subjects Committee of the University of

Toledo and supported by a research grant provided by the Applied Biomechanics Laboratory of the University of Toledo.

Table 2. Frequency distribution of the affected joints in the Osteoarthritic Females

AFFECTED JOINTS	FREQUENCIES
Ankle	1
Knee	9
Hip	4
Lumbar Spine	4
Thoracic Spine	2
Cervical Spine	4

Instrumentation

All individuals wore shorts and shirts but no shoes during all experimental conditions. A safety belt was attached to each subject's waist while walking on a motor-driven treadmill (Cambridge, Model 3050). A low mass accelerometer (Endevco, 7265A Model), encased in balsa wood, was secured via a velcro strap to the left tibial tubercle of each subject. The balsa wood provided protection for the instrument, enabled consistent anatomical placement and minimized movement of the accelerometer. During testing, the accelerometer was connected to a computer system and data were collected and analyzed at a sampling rate of 500 Hz.

Testing Protocol

Each person appeared at the Biomechanics Laboratory of the University of Toledo once for approximately one and a half hour of which 30 minutes were the total practice and testing periods of time. The remaining time was devoted to subject preparation and resting, as well as calibration of testing equipment and alteration of experimental conditions.

Each subject walked on the treadmill at grades 0° (level), $+6^{\circ}$ (uphill) and -6° (downhill) and at speeds of 1.5 and 2.5 miles per hour while having an accelerometer attached to the left tibial tuberosity and later to the middle of the forehead. These speeds were chosen based on pilot work, and represented slow and fast walking for

our groups of middle-aged women. There were 12 experimental conditions randomly assigned (2 speeds x 3 grades x 2 accelerometer placements) for each individual. Prior to each trial, a practice period of 30 seconds to one minute was provided for each person to become familiar with the degree of elevation and speed of treadmill. Following this, the accelerometer data were collected during walking for a period of 100 to 110 seconds during each experimental condition.

Experimental Design and Statistical Analysis

The experimental design was a three factorial mixed design. There were two within subjects factors (repeated measures) and one between subjects factor. The first factor (between subjects) was the type of health status (osteoarthritic and healthy). The second factor (within subjects) referred to the elevation of the readmill (0° , $+6^{\circ}$, and -6°). The third factor (within subjects) involved the speed of the treadmill (1.5 and 2.5 miles per hour).

The evaluation of the recorded deceleration signal involved calculation of the peak deceleration (shock) characteristics resulted from ground contact. The statistical analysis included a $2 \times 3 \times 2$ ANOVA with the Tukey post-hoc test once significant differences were detected. The dependent variables were the peak deceleration at tibia and forehead, expressed in g units.

RESULTS

Table 3 shows the mean peak shank deceleration values for healthy and osteoarthritic women, for all subjects between fast and slow speeds and for all participants among level, uphill and downhill walking. Healthy and osteoarthritic women had similar peak shank values. Fast walking produced 95% higher peak shank deceleration whereas during uphill and downhill ambulation the peak shank deceleration values were respectively 22% and 12.5% higher than level walking.

A summary of the three-way ANOVA for peak shank deceleration with level of significance

set at p=0.05 is shown in Table 4. The main effects of speed, grade of ambulation and speed by grade interaction were statistically significant (p<0.05 and p<0.01).

Table 3. Means and standard deviations of peak tibial and head deceleration values (g units) for health status, ambulation speed and surface inclination.

VARIABLE	Tibial Deceleration	Head Deceleration
Health Status		
Healthy	2.83 ± 0.19	0.81 ± 0.06*
Osteoarthritic	2.78 ± 0.23	0.66 ± 0.05*
Ambulation Speed		
Slow	1.91 ± 0.31**	0.51 ± 0.07**
Fast	3.71 ± 0.23**	0.97 ± 0.07**
Surface Inclination		
Level (0°)	2.46 ± 0.42*	0.78 ± 0.12**
Uphill (6°)	3.15 ± 0.57*	0.62 ± 0.09**
Downhill (-6°)	2.81 ± 0.39*	0.81 ± 0.13**

* p<0.05 level of significance

** p<0.05 level of significance

Table 3 also shows the mean peak head deceleration values for healthy and osteoarthritic women, for all subjects between fast and slow speeds and for all participants among level, uphill and downhill walking. Healthy women had 18.2% higher peak head deceleration values than osteoarthritic women. Fast walking produced 47.8% higher peak head deceleration than slow walking whereas during uphill and downhill ambulation the peak head deceleration values were respectively 11.2% lower and 3.4% higher than level walking.

A summary of the three-way ANOVA for peak head deceleration with level of significance set at p=0.05 is shown in Table 5. The main effects of health status, speed, grade of ambulation and speed by grade interaction were statistically significant (p<0.05 and p<0.01).

Table 4. Summary of three-way ANOVA with repeated measures for peak tibial deceleration

SOURCE	SS	DF	MS	F
Between Subjects	150.15	19		
Variable P	0.07	1	0.07	7.85E-03
Subjects Within Groups	150.08	18	8.34	
Within Subjects	195.36	100		
Variable Q	96.65	1	96.65	71.31**
P X Q	0.08	1	0.07	0.05
Q X Subjects Within Groups	24.39	18	1.36	
Variable R	9.42	2	4.71	3.72*
P X R	3.73	2	1.86	1.48
R X Subjects Within Groups	45.51	36	1.2	
Q X R	4.94	2	2.47	8.69**
P X Q X R	0.42	2	0.21	0.74
QR X Subjects Within Groups	10.23	36	0.28	
Total	345.51	119		

* p<0.05 level of significance

** p<0.05 level of significance

P = Health Status (i.e. healthy and Osteoarthritic)

Q = Speed of Walking

R = Grade of Surface

DISCUSSION

This study investigated the influence of varying walking conditions on shock generation and absorption characteristics of middle-aged women who were healthy or diagnosed as osteoarthritis but their symptoms were not severe to be considered candidates for surgery.

Table 5. Summary of three-way ANOVA with repeated measures for peak head deceleration

SOURCE	SS	DF	MS	F
Between Subjects	3.28	19		
Variable P	0.70	1	0.70	4.87*
Subjects Within Groups	2.58	18	0.14	
Within Subjects	8.92	100		
Variable Q	6.42	1	6.42	257.34**
P X Q	0.01	1	0.01	0.05
Q X Subjects Within Groups	0.45	18	0.03	
Variable R	0.88	2	0.44	26.62**
P X R	0.04	2	0.02	1.11
R X Subjects Within Groups	0.59	36	0.01	
Q X R	0.19	2	0.09	9.88**
P X Q X R	3.47E-03	2	1.73-03	0.19
QR X Subjects Within Groups	0.33	36	9.4	
Total	12.20	119		

* p<0.05 level of significance

** p<0.05 level of significance

P = Health Status (i.e. healthy and Osteoarthritic)

Q = Speed of Walking

R = Grade of Surface

Data, collected via accelerometry, have indicated that both group of subjects collectively presented similar values of peak tibial deceleration during ambulation.

Specifically, the healthy persons had an average peak tibial value of 2.8304 g whereas the osteoarthritic individuals displayed similar mean peak tibial value of 2.7837 g. These results are in accordance to those reported in related literature¹⁹⁻²¹ and were expected because the anatomic units of foot and shank will absorb approximately

the same amount of ground reaction forces unless a pathology is present in these structures, or unless the velocities of the foot and shank in both groups are unequal at ground contact. Both of the tested groups had about the same mean weight (Table 1), and no considerable pathological deformities in their feet and/or shanks (Table 2). Although the velocities of the foot and shank at ground contact were not calculated, based on the fact that both groups were tested at the same walking speeds, it is speculated that these velocities were probably equal for both groups. Thus, the ground reaction forces produced nearly the same magnitude of shock once transmitted to the tibial tuberosity. Indeed, the three-way ANOVA, in Table 4, statistically confirmed the similarity of tibial peak deceleration of both groups ($p>0.05$).

Results of mean peak head deceleration revealed that there were statistically lower values ($p<0.05$) in osteoarthritic women than in healthy individuals. Apparently, kinematic adjustments occurring in the spine and/or pelvis of osteoarthritic females²² as well as muscle function²³⁻²⁵ may have accounted for the greater absorbed deceleration values although the present study has not examined kinematic or EMG parameters in both groups. Nevertheless, the recorded peak shock head values agree with those reported in scientific related literature^{26,21,27}.

Regarding walking speed, it was demonstrated that slow walking produced statistically lower ($p<0.01$) tibial (1.9096 g) and head deceleration (0.5050 g) than fast walking (3.7044 g and 0.9677 g respectively). The outcome of these results was expected since fast walking always generates greater ground reaction forces than slow walking²⁸. Similar results in related literature concerning impact loading at shank and head sites are also reported by other investigators²⁹⁻³².

The effect of walking surface slopes on deceleration characteristics was also examined in this study. It was reported that peak shank deceleration values were significantly lower ($p<0.05$) at level grade (2.4617 g) than those recorded during uphill (3.1478 g) and downhill (2.8116 g) walking. In contrast, significantly lower peak head

deceleration values ($p<0.01$) were observed during uphill walking (0.6165 g) than those recorded during level (0.7823 g) and downhill (0.8102 g) walking. By subtracting the results in the three grades of ambulation between the sites of shank and head, it was clearly shown that the highest values of shock generation and attenuation was recorded during uphill walking (2.5313 g) whereas shock absorbed in downhill and level walking was 2.1014 g and 1.6794 g respectively. These findings are in accordance to those reported in scientific related literature regarding slope of walking surface^{30,33}. Therefore, it is safe to recommend level walking to middle-aged osteoarthritic women as a mode of exercising because it produces the least stress and loads the musculoskeletal system minimally.

CONCLUSIONS

Based on the results of the study following conclusions were drawn:

1. Tibial peak deceleration is the same for the healthy and osteoarthritic females.
2. Osteoarthritis exhibit lower values of peak head deceleration than healthy women. Kinematic adjustments may contribute to these findings.
3. Slow walking is less stressful than fast walking in middle-aged females. Thus, slow walking is highly recommended in patients suffering from osteoarthritis.
4. Level walking produces the least loading on the human locomotor system. Uphill walking generates the highest impact forces in elderly women and thus, it should be avoided.

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Conflict of interest

The authors declare that they have no conflict of interest

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