Gait Analysis in Patients with Diabetic Peripheral Neuropathy

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Abstract

**Background:** Neuropathies are the most common complication of diabetes mellitus (DM) which can affect a variety of body systems, including the locomotor, sensory, vestibular and visual system leading to poor balance which can lead to gait abnormalities causing great morbidity and worsening patients’ quality of life.

**Aim of the Work:** We aimed to analyze and compare kinematic gait parameters in diabetic peripheral neuropathic patients and healthy controls.

**Subjects and Methods:** Sixty subjects were participated in this study, their ages ranged from 40-60 years. Thirty subjects were diabetic peripheral neuropathic patients, the other thirty subjects were age, weight, height and gender matched healthy controls. Gait analysis was performed for both groups using three-dimensional motion analysis system which consists of: Motion capture unit (a camera system), wand-kit (L-shaped wand and T-shaped wand), serial interface adaptor, personal computer and reflective markers. The measurement procedures included system calibration, application of markers, first trial to adjust walking path, the qualysis trac capturing image, data processing, editing, calculation and results.

**Results:** The study revealed statistically significant differences between both groups in all variables. Diabetic group had significantly lower values than the control group in the following parameters: Walking velocity (m/sec), cadence (step/min), stride length (m), and angles of the ankle and knee joints (degrees) while for stance time percentage and time of gait cycle (sec), the diabetic group had significantly higher values.

**Conclusions:** Diabetic peripheral neuropathic patients’ had significantly lower values of all kinematic gait analysis variables than the healthy controls except for stance time percentage and time of gait cycle which were significantly higher than the control group.

**Key Words:** Diabetes mellitus – Peripheral neuropathy – Gait analysis.

**Introduction**

**DIABETES** mellitus is a metabolic disorder characterized by hyperglycemia, hyperlipidemia, and hyperaminoacidemia resulting from defects in insulin secretion, action or both. The chronic hyperglycemia of diabetes is associated with long term damage and failure of various organs especially eyes, kidneys, nerves, heart and blood vessels [1]. It is one of the fastest growing public health problems in both developed and developing countries. It is estimated that the number of people with diabetes will reach 300 millions by 2025 [2].

Neuropathies are the most common complication of diabetes mellitus (DM). Neuropathies related to DM affect up to 50% of patients both with type 1 and type 2 DM. Neuropathies also cause great morbidity because the symptoms severely decrease patients’ quality of life [3].

In addition to the autonomic nervous system, these neuropathies also affect a variety of body systems, including the vestibular system [4] and vision [5]. Muscle strength can also be reduced in diabetes [4]. The overall effect of eye, motor and vestibular impairment is poor balance [6,7]. This is made worse if there is diminished sensation in the feet [8]. Either together or individually, these can lead to gait abnormalities [9,10].

Patients with diabetes and peripheral neuropathy have a high incidence of injuries during walking. People with diabetes are 15 times more likely to report a fall-related injury (fracture, sprained ankle, cuts and bruises) during standing and walking when compared to people without diabetes. In addition, peripheral neuropathy is a risk factor for developing plantar ulcers. Most of these ulcers are thought to develop during walking [7].
Normal walking is the end product of a healthy neuro-musculo-skeletal system, which requires both sensory input to modify learned motor patterns and muscular output to execute the desired action. An intact central and peripheral nervous system to initiate and control the movement, adequate muscle strength, bones and joints moving in full range are the necessities for normal locomotion which is the most natural daily activity for humans [11].

Diabetes has been associated with reductions in ankle muscular strength and ankle mobility, which was included among the main causes that lead to critical changes in walking pattern [12]. Reduced muscle strength around the ankle joint, especially tibialis anterior, may be responsible for the gait deviation of diabetic patients. Tibialis anterior muscle is innervated by peroneal nerve which is the first nerve to show electrophysiological alterations in patients with diabetic motor neuropathy. Because neuropathic patients show muscle weakness of the tibialis anterior and gastrosoleus muscle groups, there is a general lack of foot and ankle control in the heel strike phase as flat foot [12-14]. Add to this, the lack of sensorial and kinesthetic information from the ankle, this certainly will impair gait [11].

Reduced strength of ankle plantar flexion have leads to adoption of a “hip strategy” of walking, whereby the leg is pulled forward from the hip using hip flexor muscles (hip strategy), rather than being pushed forward by the foot using plantarflexor muscles (ankle strategy). The altered gait strategy suggests that diabetic subjects adopt a “slowness strategy”. This allow them to reduce their disequilibrium so they might have more time to react as they have a prolonged reaction time [11,15,16].

Patients with diabetes may present deficits in gait long time before objective loss of sensation in the feet and this could be explained by damage of vestibular system and somatic and autonomic nervous systems due to damage to the microcirculation associated with poor glycemic control due to dysfunction of endothelial cells and blocking of the normal nitric oxide pathways that cause vasodilatation [17]. These neuropathies cause slowing in conduction in the peripheral nervous system in diabetic patients long before noticeable sensory and motor loss. Slower conduction would slow reflexes and motor control schemes and cause errors in movement [18]. This reduction in nerve blood flow that causes somatic and autonomic nervous system damage is believed to also be linked to formation of nonenzymatic glycation end products. There is also some indication that there is a deprivation of nerve growth factors in subjects with type 1 and type 2 diabetes. So, the changes that occur in gait of people with diabetes may be the result of more central damage to the vestibular, somatic, and autonomic systems as a result of microcirculation changes associated with poor glycemic control and not only the result of peripheral insults [3,19,20].

Besides well-known dramatic alterations in all components of the peripheral nerves, diabetes mellitus have a spectrum of hyperglycemic complications including the mechanical characteristics of bones and soft tissues, hyperostosis, the vasculature at both a microscopic and a macroscopic level, the immune system, and the fundamental processes of wound healing. The accumulation of advanced glycation end products (AGEs) in collagen may have played a role in limiting joint mobility in patients with diabetes and attributed this syndrome to changes in the ultrastructure of collagen in various periarticular tissues [21]. It has been shown that connective tissue of patients with diabetes mellitus have structural changes such as increased collagen type III content, loss of fascicular organization, increased cross-linking and breakdown in collagen fibrils in diabetic heel samples. These structural alterations of connective tissue may be responsible for the decrease in ankle mobility [11].

The role of physiotherapy in diabetic care is to reduce immobilization effects, maintain functional capacity and minimize diabetes-related complications. The physiotherapist also has a role in providing advice about exercise and daily living activities. The fundamental principle of rehabilitation is to improve quality of life while diminishing the health care burden. By reducing the heightened risk of falling, the fall related injuries during walking or standing and the fear of falling, one could improve quality of life in diabetic patients and reduce health care costs [2].

Gait analysis can provide a good objective and quantifiable evaluation of function in diabetic peripheral neuropathy [22]. The technology that supports human motion analysis has advanced dramatically in the past two decades. Motion systems are of many varieties and software is abundantly available for measuring and recording particular body areas or whole systems during a variety of activities [23].

It is therefore imperative to search for gait characteristics in diabetic patients with peripheral...
neuropathy in order to understand diabetic patients’ gait abnormalities and their increased risk of falls. The concept of considering how the diabetic disease process affects not only the foot but the movement pattern of the entire lower extremity is fundamental in order to determine the most optimal treatment approach for these patients and to develop more focused intervention strategies.

**Material and Methods**

Thirty patients (16 males and 14 females with mean age 55.033 ± 2.36 years) with diabetic peripheral polyneuropathy (diabetic group) and thirty healthy control subjects (16 males and 14 females with mean age 53.833 ± 3.86 years), (control group). Thorough history taking, clinical examination and measurement of fasting and two hours postprandial blood glucose levels were done to all participants. The study was conducted at Internal Medicine Department, Faculty of Medicine, Cairo University and motion analysis lab, Faculty of Physical Therapy, Cairo University.

**Inclusion criteria:** Inclusion criteria for the diabetic group included being diagnosed with diabetic peripheral polyneuropathy based on clinical examination and nerve conduction studies, has controlled blood glucose levels and able to walk independently without pain or an assistive device (e.g., walker or crutches). Inclusion criteria for the control group were no history of diabetes and ability to ambulate independently without pain or use of an assistive device.

**Exclusion criteria:** They included foot ulceration, transmetatarsal amputation, neuropathic arthropathy (Charcot's joints), orthopaedic or surgical problems influencing gait parameters, non-diabetes related neuropathy, non-diabetes related vestibular or vision disorder, and any other neurological diseases influencing the gait.

All subjects of diabetic and control groups underwent gait analysis. They received a through explanation of evaluation procedures. The groups were comparable for age, height, weight, body mass index and gender.

- **Weight and height scale:** For measuring body weight, height and body mass index (BMI).
- **Opto-electronic motion analysis system:** Qualisys Motion Capture System was used to measure joint angles of the ankle and knee joints during gait and other gait parameters (walking velocity, cadence, stride length, stance time and the time of gait cycle). This system consists of the following parts:
  - ProReflex MCU (motion capture unit) 120: Consists of a camera system having three cameras (units) to perform multi camera measurements. The basic principle of the ProReflex MCU 120 is to expose reflective markers to infrared light and to detect the light reflected by the markers. The 2-dimensional (2-D) image of the markers was processed by the MCU and the 2-D coordinates of each marker were output as a data stream. The 2-D data from each camera in such a system was retrieved simultaneously and combined for calculating the 3-dimensional (3-D) positions of the markers [24].
  - A wand-kit: A specific kit that is used for the calibration of the system. It consists of two parts: L-shaped wand (lined by four fixed markers at a known distance and represents X and Y coordinates) for defining the calibration coordinate system and T-shaped wand (has two markers, one at each end, and handle) used to provide the camera system with measurement points to use for the calibration process.
  - ABC-530 serial interface adaptor: A communication card, which must be mounted in the personal computer (PC).
  - Personal Computer (PC) with the Q (Qualisys) Trac, Q Gait (2.0) and Q Tools soft wares.
  - Q Trac, Q Gait (2.0) and Q Tools soft wares: Softwares developed for analyzing the motion pattern of human gait as retrieved by the ProReflex camera system [24].
  - Reflective markers: They are small balls capable of reflecting the infrared light sent from the ProReflex Cameras. They were adhered to the bony landmarks by using adhesive double face plaster.
  - Measurement procedures: The cameras were placed at suitable position to view the measurement volume which must cover the full body of the patient during performing many gait cycles. Patient was asked to stand at the first border of the walk way and Q trac was initiated at the calibrating mode.

For each subject, seven reflecting dots (markers) were placed on the following special bony landmarks of patient’s body on the side of the body that faced the cameras: Greater trochanter, superior edge of the patella, lateral aspect of the knee joint line, tibial tuberosity, lateral malleolus, dorsum of foot between the bases of the 2nd and 3rd metatarsal bones and over heel (posterior of calcaneus) [11].
Once the cameras were set up, the measurement volume was calibrated as the following: Firstly, L-shape wand was placed in the middle of the walkway at the force plate form with the x-axis in the walking direction. Then, T-shape wand was moved in x, y and z direction so that, the wand markers were oriented in all three directions of the measurement volume. During this procedure, the therapist moved around in the measurement volume to allow all cameras to L-shape and T-shape of the wand during the calibration. Then the therapist move the wand in the suggested area of measurement as much as possible so that, all the cameras connected to the system can pick up the marker position in various locations. A suitable set up for a good calibration of all cameras took 10-20 seconds for the calibration sequence.

Subjects were instructed to walk on the walkway inside the lab bare feet at their natural or comfortable walking speed (self-selected speed) [25]. Three to five walks along the walkway were allowed prior to recording of data, so that subjects were familiar to the walkway and then they were asked to begin from the starting position which was determined during the test trials and when they passed the starting position, the Qtrac measurement was started and they were let to continue walking until several meters after the volume to allow the Qtrac measurement to be completed.

- **Data processing and editing:** The data was processed, analyzed and then edited in Q view software.

- **Calculation and results:** The 2-D data were automatically transferred to the 3-D where marker names were identified and exported to the Q gait program for further analysis. The following kinematic gait parameters were calculated:
  - Spatio-temporal (distance and time) parameters which included: Walking velocity (m/sec), cadence; number of steps per minute (step/min), stride length (m) which is the length of a gait cycle (a cycle starting from an event by one limb to the next occurrence of the same event by the same limb as from heel strike to heel strike on the right foot), stance time (%) (the percentage of period of time taken by the limb in contact with the floor from the total time of the gait cycle), and gait cycle time (sec).
  - Angles of the ankle and knee joints during gait. Joint angle is the angle between the line of the proximal and distal segments of a joint [2,3,26].

**Statistical analysis:** Data were collected for both groups. Collected data were fed to the computer, manipulated and analyzed. The mean, and standard deviation were calculated. The comparison was made by independent $t$-test to compare the significance of difference between both groups (Diabetic group and control group). Statistical significance was established at the convention <0.05 level.

**Results**

The results are shown in Tables (1-5).

| Table (1): Clinical criteria for the diabetic and control groups. |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| **Variable**               | **Diabetic group**          | **Control group**           | **t**          | **p**       |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Age (year)                 | Mean±S.D 55.033±2.36        | Mean±S.D 53.833±3.86        | 1.453          | >0.05       |
| Height (m)                 | 1.672±0.069                 | 1.693±0.053                 | 0.129          | >0.05       |
| Weight (Kg)                | 83.333±6.183                | 80.467±9.919                | 0.343          | >0.05       |
| BMI (Kg/m$^2$)             | 29.808±3.834                | 28.07±3.465                 | 1.382          | >0.05       |

**Gender:**
- Male (n) 16
- Female (n) 14

SD = Standard deviation. $p$-value = Level of significance.

<p>| Table (2): Mean values of walking velocity (m/sec) for the diabetic and control groups. |
|-----------------------------|-----------------------------|-----------------------------|</p>
<table>
<thead>
<tr>
<th><strong>Group</strong></th>
<th><strong>Statistical value</strong></th>
<th><strong>Walking velocity (m/sec)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetic group</td>
<td>Mean±SD 0.83±0.122</td>
<td>2.285</td>
</tr>
<tr>
<td>Control group</td>
<td>Mean±SD 1.106±0.137</td>
<td>8.25</td>
</tr>
<tr>
<td>$t$-test</td>
<td>$t$-value 0.137</td>
<td>$p$-value &lt;0.05*</td>
</tr>
</tbody>
</table>

$m$/sec = Meter per second. SD = Standard deviation. $p$-value = Level of significance. *Significant at $p$-value <0.05.

| Table (3): Mean values of cadence (step/min) stride length (m) and stance time% for the diabetic and control groups. |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| **Group**                  | **Statistical value**       | **Cadence (step/min)**      | **Stride length (m)**       | **Stance time%**       |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Diabetic group              | Mean±SD 88.5±4.493          | 1.016±0.073                 | 68.967±23.2                |
| Control group               | Mean±SD 104.6±6.355         | 1.29±0.1                    | 63.567±22.285              |
| $t$-test                    | $t$-value 11.33              | $p$-value <0.05*             | 7.522                      |

Step/min = Step per minute. m = Meter. % = Percentage. SD = Standard deviation. *Significant at $p$-value >0.05.

<p>| Table (4): Mean values of gait cycle time (sec) for the diabetic and control groups. |
|-----------------------------|-----------------------------|-----------------------------|</p>
<table>
<thead>
<tr>
<th><strong>Group</strong></th>
<th><strong>Statistical value</strong></th>
<th><strong>Time of gait cycle (sec)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetic group</td>
<td>Mean±SD 1.387±0.12</td>
<td>4.86</td>
</tr>
<tr>
<td>Control group</td>
<td>Mean±SD 1.222±0.142</td>
<td>2.285</td>
</tr>
<tr>
<td>$t$-test</td>
<td>$t$-value 4.86</td>
<td>$p$-value &lt;0.05*</td>
</tr>
</tbody>
</table>

Sec = Second. SD = Standard deviation. *Significant at $p$-value <0.05.
The findings of this study are similar to those of Salsich and Mueller [21] who compared diabetic peripheral neuropathic patients to age matched control group in passive ankle stiffness and ankle joint angle. Although the methods of measurement were different from current study methods, they found significant reductions in walking velocity and ankle joint angle in diabetic group.

The current study results are supported by the work of Meier, et al. [15] who compared the gait of diabetic patients with healthy elderly subjects. The participants walked at their own pace along a walkway and stopped in front of a marked stopping line while kinetic and kinematic data were recorded. The diabetic subjects approached the stopping line more slowly, exhibited a weaker maximal braking force and a prolonged time to develop this force. Changes in gait termination parameters and the increased overshoots documented the pathology-related decline in postural stability.

The changes reported in diabetic gait in this study confirm the findings of Kwon, et al. [30] who reported lower knee extension movements in subjects with diabetic neuropathy compared to control subjects and observed a decreased plantar flexor movement during walking in patients with diabetes, which could be related to decreased strength in calf muscles. They reported also lowered walking velocity in diabetics.

Our results are similar to those reported by Menz, et al. [10] who compared the spatio-temporal parameters of gait of 30 elderly diabetics with peripheral neuropathy to 30 age-matched controls and they found significant differences between both groups.

In a study done by Petrofsky, et al. [3] they compared autonomic, endothelial function and gait characteristics in diabetics to healthy controls. Their results confirmed our study results and their data also showed at least a 50% impairment in local tissue blood flow and autonomic function in subjects with diabetes compared to control subjects.

Our findings are in agreement with those of Yavuzer, et al., who compared gait deviations of diabetes mellitus (DM) patients with diabetic peripheral neuropathy, diabetic without peripheral neuropathy and healthy controls. They revealed that both diabetic groups had slower gait, shorter steps and limited knee and ankle mobility than control group. They concluded that neuropathy may not be the only reason for gait deviations in DM patients [11].

Discussion

Gait is controlled through information received from the vestibular, visual and somatosensory systems with final control mediated through the motor system. Any impairment in any of these systems would have a negative effect on gait, altering movement in the limbs as well as pressure distribution on the foot. Since all elements of the nervous, vestibular and visual systems can be damaged in both Type 1 and Type 2 diabetes, so, the effects of diabetic complications might be expected to have a measurable effect on gait patterns [3].

Studying diabetic individuals' gait parameters could be useful in predicting falling, and could also facilitate the understanding of the causes and underlying mechanisms of heightened fall risk in that population.

The results of the present study revealed a statistically significant decrease of walking velocity (m/sec), cadence (step/min), stride length (m), angles of ankle and knee joints (degrees) during gait while for stance time % and time of gait cycle (sec), there was a statistically significant increase in diabetic group compared with control group.

In contrast to our results, Dingwell, et al., evaluated kinematics of diabetic gait. They found non-significant decrease in gait cycle time (sec) in evaluated diabetic group (1.22sec for the control group versus 1.21sec for the diabetic group) [27]. However, in other studies by Dingwell, et al. [28] and Dingwell and Cavanagh [29] they agreed with the current results. They supported the hypothesis that the gait patterns of these patients reflect not only the effects of the neuropathy itself, but also of locomotor control strategies developed by these subjects to compensate for their sensory loss. The primary compensatory mechanism adopted by these patients appears to be a decrease in self-selected walking speed to maintain dynamic stability of the upper body during walking.

<table>
<thead>
<tr>
<th>Group</th>
<th>Statistical value</th>
<th>Ankle joint angle (degrees)</th>
<th>Knee joint angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetic group</td>
<td>Mean±SD</td>
<td>22.2±1</td>
<td>44.4±6.061</td>
</tr>
<tr>
<td>Control group</td>
<td>Mean±SD</td>
<td>28.7±3.46</td>
<td>49.967±3.746</td>
</tr>
<tr>
<td>t-test</td>
<td>t-value</td>
<td>9.30</td>
<td>4.975</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>&lt;0.05*</td>
<td>&lt;0.05*</td>
</tr>
</tbody>
</table>

SD = Standard deviation.
*Significant at p-value <0.05.

Table (5): Mean values of ankle and knee joints angles during gait (degrees) for the diabetic and control groups.
The current study results are in agreement with that of Wrobel, et al. [26] who described the conservative gait pattern adopted in male diabetic patients. Because of the older age of their sample (elderly men), the mean values of their results were lower than the results of our study even for normal gait. The walking velocity for example was 0.68 m/sec in conservative gait versus 0.91 m/sec in normal gait while in the present study it was 0.83 m/sec in diabetics versus 1.106 in healthy matched controls.

The results of the present study are in agreement with Allet, et al. [31] in their systemic review about gait deviations in diabetic patients and conducted a clinical observation study as gait was assessed on three different real life surfaces (tar, grass and stones). Diabetic patients' gait parameters differed significantly from those of healthy controls. They concluded that walking in real life conditions revealed gait difficulties in patients with diabetes before neuropathy was clinically detectable and clinicians should be aware that diabetic individuals' gait capacity decreases and fall risk increases at an early stage of the disease.

The decreased gait velocity in diabetic patients compared to healthy controls found in our study is not only statistically significant but also of great clinical relevance. A decrease of 0.276 m/s represents a reduction of 25% compared to normal walking speed (1.106 m/s). It is very likely that such reduction in gait speed could influence individuals' activities of daily living.

If gait analysis is included in the assessment of patients with diabetes mellitus and gait alteration is detected, it should be taken as a warning sign. This is reported to be related to a heightened fall risk [32]. The application of prevention strategies is thus shown to be imperative.

**Summary:**

Diabetes mellitus is associated with several neuromusculoskeletal impairments, physical disability and lower health-related quality of life. Connective tissue disorders, neuropathy, vasculopathy or combinations of these problems may cause these musculoskeletal alterations and uncoordinated gait which increase the risk of foot ulcers and falling.

This study was designed to investigate and compare between diabetic peripheral neuropathic patients and healthy controls in kinematic gait parameters [walking velocity (m/sec), cadence (step/min), stride length (m), stance time %, time of gait cycle (sec) and joint angles of ankle and knee joints (degrees) during gait]. Sixty subjects, their age ranged from 40-60 years, were enrolled into the study procedures. Thirty of them were diabetic peripheral neuropathic patients (diabetic group) and the other thirty were healthy controls (control group). Gait analysis was performed for both groups using three-dimensional motion analysis system (Opto-electronic motion analysis system).

The results showed that there were statistically significant differences between both groups in all variables. Diabetic group was significantly lower than the control group in the following parameters: Walking velocity (m/sec), cadence (step/min), stride length (m), and angles of the ankle and knee joints (degrees) while for stance time percentage and time of gait cycle (sec), diabetic group was significantly higher than control group.

**Conclusion and Recommendations:**

Diabetic peripheral neuropathic patients' gait significantly differs from healthy controls in kinematic gait analysis variables.

Patients with diabetes mellitus should start mobility and strengthening exercises in early stages. Because peripheral neuropathy affects primarily the distal musculature (i.e., the foot and ankle), the most advantageous exercise might focus on the hip and knee. So, in terms of therapeutic aspects, strengthening of the hip and knee flexors to compensate for the inefficiency of the ankle together with balance and coordination exercises, and better glycemic control might help to decrease morbidity of diabetic patients giving rise to long term health and better quality of life.

Multidisciplinary approaches are requisite in determining the underlying mechanisms of gait abnormalities in diabetic patients. Also, clinical studies should be encouraged to analyze the gait of type 1 versus type 2 diabetic patients.

Evaluating gait parameters in diabetic patients under various real life conditions (e.g. walking on different road surfaces, grass, ramps and stairs), rather than in specialized gait laboratories is recommended, since falls occur mostly during a patient's daily routine.

A comparison of these data to those of people without clinical peripheral neuropathy may provide further insight into the origin of these gait deviations. Also, to demonstrate the relation between disease severity and gait alterations a three-group comparison (diabetics with, without diabetic peripheral neuropathy and healthy controls) is nec-
Reference
