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Review

Biomechanical characteristics of peripheral diabetic neuropathy: A systematic review and meta-analysis of findings from the gait cycle, muscle activity and dynamic barefoot plantar pressure

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ABSTRACT

Background: Diabetic peripheral neuropathy is an important cause of foot ulceration and limb loss. This systematic review and meta-analysis investigated the effect of diabetic peripheral neuropathy on gait, dynamic electromyography and dynamic plantar pressures.
Methods: Electronic databases were searched systematically for articles reporting the effect of diabetic peripheral neuropathy on gait, dynamic electromyography and plantar pressures. Searches were restricted to articles published between January 2000 and April 2012. Outcome measures assessed included spatiotemporal parameters, lower limb kinematics, kinetics, muscle activation and plantar pressure. Meta-analyses were carried out on all outcome measures reported by ≥3 studies.
Findings: Sixteen studies were included consisting of 382 neuropathy participants, 216 diabetes controls without neuropathy and 207 healthy controls. Meta-analysis was performed on 11 gait variables. A high level of heterogeneity was noted between studies. Meta-analysis results suggested a longer stance time and moderately higher plantar pressures in diabetic peripheral neuropathy patients at the rearfoot, midfoot and forefoot compared to controls. Systematic review of studies suggested potential differences in the biomechanical characteristics (kinematics, kinetics, EMG) of diabetic neuropathy patients. However these findings were inconsistent and limited by small sample sizes.
Interpretation: Current evidence suggests that patients with diabetic peripheral neuropathy have elevated plantar pressures and occupy a longer duration of time in the stance-phase during gait. Firm conclusions are hampered by the heterogeneity and small sample sizes of available studies.

1. Introduction

One of the many consequences of diabetes is the onset of diabetic peripheral neuropathy (DPN) (Shenoy, 2012). The prevalence of DPN ranges from 13 to 68% in diabetes populations (van Dieren et al., 2010). Peripheral neuropathy affects the sensory, motor, and autonomic components of the nervous system, manifesting as a loss of protective sensation, intrinsic foot muscle dysfunction and anhydrosis of the foot (Shenoy, 2012). These manifestations often lead to bony deformities and high plantar pressure areas which result in skin breakdown and ulceration (Boulton et al., 2005). It is believed that the majority of diabetic foot ulcers develop as a result of the repetitive action of mechanical stress (pressure) during gait, in the presence of peripheral neuropathy or loss of protective sensation (Armstrong et al., 2004). Lower-limb amputations in people with diabetes are typically preceded by foot ulceration, suggesting that better understanding of the mechanisms of ulcer development are of vital importance (Singh et al., 2005). This includes better understanding of the biomechanical components (Formosa et al., 2013).

It has been postulated that DPN-related changes in the lower limbs may lead to functional gait variations; predominantly related to reduced range of movement of joints, reduced active muscle power and changes

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in gait mechanics (Andersen, 2012). The biomechanical changes resulting from DPN may translate to increased plantar pressures in the foot, which contributes to the pathogenesis and development of foot ulcers, especially in the forefoot (Van Deursen, 2004). In particular, the first metatarsophalangeal joint has been implicated as a site of biomechanical dysfunction leading to elevated plantar pressures during gait, promoting ulceration at this site (Turner et al., 2007). Therefore, we hypothesised that reductions in spatiotemporal parameters, increases in kinetics (specifically the vertical ground reaction force and joint moments), and reductions in kinematics of the lower limb (evident as restrictions in the sagittal plane) and altered dynamic electromyography (EMG) findings in those with DPN may manifest from or contribute towards altered plantar pressure loading in this population (Cavanagh et al., 2000). Therefore, this systematic review and meta-analysis aimed to assess the effect of DPN on gait (spatiotemporal parameters, joint angular kinematic and kinetics), dynamic EMG (muscle activation and deactivation patterns) and dynamic barefoot plantar pressures (plantar foot pressures during gait). We sought case–control studies comparing patients with DPN to those with diabetes mellitus without neuropathy (diabetes mellitus controls) (DMC) or healthy controls (HC).

2. Methods

2.1. Literature search strategy

Electronic databases (Ovid, CINAHL, PubMed, Scopus and Google Scholar) were searched systematically by the first author for articles published between January 2000 to April 2012, reporting studies on DPN in the three biomechanical areas of gait, dynamic EMG and plantar pressure. The initial search was conducted in April 2012. An additional search was conducted in January 2013 to ensure that any further articles were also assessed for inclusion prior to publication. No new articles were found. Search results were restricted to articles published between January 2000 and January 2013. Publications prior to the twenty first century were not included to restrict the focus of the review to the most recent findings from studies which assessed gait using current technology, which is more reliable and comprehensive. This is especially true in relation to three dimensional joint angular kinematic analysis which was introduced at around this time (Sutherland, 2001, 2002, 2005). The following keywords and MeSH headings were used:

1. Gait AND diabetes
2. electromyograph* AND diabetes
3. EMG AND diabetes
4. biomechanic* AND diabetes
5. kinematic AND diabetes
6. plantar pressure AND diabetes
7. (diabetes MeSH) AND 1# AND 2# AND 3# AND 4# AND # 5
8. (diabetic foot MeSH) AND 1# AND 2# AND 3# AND 4# AND # 5
9. (diabetic neuropathy MeSH) AND 1# AND 2# AND 3# AND 4# AND # 5

2.2. Selection of studies

The titles and abstracts retrieved from the initial database search were screened by the first author utilising the question 'Did the study investigate one of the three biomechanical areas of interest?' The full text was obtained for articles that remained relevant after the initial screening. One of the authors then reviewed the full text for the final decision on inclusion utilising the entry criteria. All articles meeting these initial criteria had their full-texts retrieved and were then further evaluated by two authors (MF and RC) using the inclusion and exclusion criteria below. All studies meeting the exclusion criteria were removed from the review.

The inclusion criteria were:

1. Studies published between 2000 and 2012;
2. Studies in the English language;
3. Studies reporting findings in clearly identified DPN groups in comparison to a DMC and/or a HC group using eligible inclusion and/or screening criteria;
4. Studies investigating barefoot walking. Barefoot investigations were chosen over shod as this was thought to provide insight into biomechanical parameters without the influence of shoes;
5. Studies in adult populations ($\geq$18 years old);
6. Study reported findings for at least 1 outcome measure of interest in the review.

Exclusion criteria were:

1. Any study investigating participants' gait, EMG or plantar pressure while wearing shoes, inserts or orthotic devices;
2. Any study which included current or past diabetes foot ulcer participants as a part of their DPN or DMC groups;
3. Studies that investigated movement on a treadmill;
4. Studies where reported outcome measures were not comparable with at least one outcome measure of interest and could not be converted;
5. Studies where authors were unable to provide datasets or outcome variables that were compatible for comparison (mean and standard deviation, SD), in place of missing data.

2.3. Outcome measures

Studies were included in the review if they reported at least one of the following outcome measures:

1. Spatiotemporal — walking speed (m/s) with or without stride length (m);
2. Kinetics — reported findings on net moments of force (flexion and extension) for at least one lower limb joint (ankle, knee or hip) and/or reported ground reaction force at initial contact and/or toe-off as separate values;
3. Kinematics — reported range of motion (RoM) findings for at least one lower limb joint (ankle, knee or hip) in both flexion and extension directions;
4. EMG — activation and deactivation durations of any lower limb muscle during walking in % stance or % gait cycle;
5. Plantar pressure — reported on at least one site at the rearfoot or midfoot or forefoot or in any other plantar location in either peak plantar pressure (MPP) or pressure time integral (PTI) or both.

2.4. Assessment of methodological quality of studies

Two assessors (MF and PL) independently evaluated the quality of the studies utilising a modified version of the quality assessment tool by Downs and Black (1998). The criteria within the tool which were not applicable to the studies included in this review were omitted from the analysis (see Table 1). The total quality scores were reported as an average score between the two assessors. As a simplified version of the quality assessment instrument tool by Downs and Black (1998) was utilised, the original scoring system for the tool was scaled according to a total score of 18. Therefore, a score of $\leq$7 was considered low quality, 8–11 as fair quality and >11 as good quality.

2.5. Data extraction and reporting

Data extraction was performed by the first author with assistance from a statistician (PB) for data analysis. Data were entered into tables for ease of comparison and grouping of variables. Only studies that reported the outcome measures of interest were used in the statistical analysis that followed. Descriptive characteristics of participants (age,