Clinical Biomechanics 42 (2017) 14–19

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Mechanisms of compensation in the gait of patients with drop foot

Błażkiewicz Michalina *, Wiszomirska Ida, Kaczmarczyk Katarzyna,
Grażyna Brzuszkiewicz-Kuźmicka, Wit Andrzej

Józef Piłsudski University of Physical Education in Warsaw, Department of Physiotherapy, Marymoncka 34, 00-968 Warsaw, Poland

ARTICLE INFO

Article history:
Received 21 March 2014
Accepted 31 December 2016

Keywords:
Compensation
Drop foot
Gait

ABSTRACT

Background: Drop foot is a complex syndrome, with multiple interactions between joints and muscles. Abnormalities in movement patterns can be measured using motion capture techniques, but identifying compensation mechanisms remains challenging.

Methods: In order to identify compensatory mechanisms in patients with drop foot, this study evaluated a sample of 15 such patients using a computerized gait analysis system, as compared to a group of 15 healthy subjects.

Findings: Four classes of parameters were distinguished, falling in differing intervals of percentage differences between the groups in the study. The first class comprised two kinematic parameters for which the values of percentage differences in the control group were more than 100% greater than for the patient group. The second class comprised two kinetic parameters falling in the interval of 100–49%. In the third class, in the 49–20% interval the main differences were observed for spatiotemporal parameters, whereas in the 20–4% interval the differences were distributed similarly for kinematic, kinetic and spatiotemporal parameters.

Interpretation: These differences in gait pattern between the groups may be related to both primary motor deficits and secondary compensatory mechanisms. Generally, we conclude that drop foot affects the patients' overall kinematic and kinetic gait parameters, with compensation seen as a chain originating from a change of movement within the ankle joint.

1. Introduction

1.1. Definition of compensatory mechanisms

Compensation is a strategy whereby one aims to counteract, consciously or unconsciously, certain weaknesses, frustrations, desires, or feelings of inadequacy or incompetence in one life area through gratification or excellence in another area (Adler, 2009). In terms of biomechanics, compensation is a complex process aiming to counteract deficiencies and to adapt to the environment under pathological morphological and functional conditions arising from an illness or injury. Compensation is, therefore, the body's natural ability to provide alternative means of performing lost functions, either by the damaged or injured organ itself, or through their takeover by another healthy organ (Walicki, 1975). Anochin and Agafonow (1961) argue that compensation is an innate ability of living organisms, which starts at the point of the central nervous system receiving information about a defect arising in the peripheral system. Compensation depends on many factors, the most important of which are the location and extent of the damage, the dynamics behind the defect, psychological motivation, patient age, and the correct functioning of the compensation process, whereby changes of position or movement are imposed on healthy parts of the body (Anochin and Agafonow, 1961). Compensation for dynamic disorders may involve absent muscular forces being replaced by other muscles, usually located nearby, acting in the same or similar manner, allowing the patient to execute nearly the same movement as before their illness or injury; this is known as direct compensation. If damage is sustained to the entire muscle group and there is an absence of similar forces, indirect compensation occurs, in which the movement is replaced by a single movement or several movements best suited to performing the desired function.

1.2. ‘Drop foot’ syndrome

Patients with paresis of the tibialis anterior muscle exhibit a certain dropping of the foot during walking, a syndrome known as ‘foot drop’ or ‘drop foot’ (Perry, 1992). In this case, direct compensation means that the dorsiflexion function is taken over by the extensor hallucis longus and extensor digitorum longus muscles. Patients with paralysis of all muscles responsible for the dorsiflexion function, however, may exhibit indirect compensation, in which the angles of the hip and the knee joints increase during gait with the damaged limb (Sabir and Lyttle, 1984). Generally, drop foot describes a motor deficiency caused by a total or partial central paralysis of the muscles innervated by the common peroneal nerve, i.e. the anterior tibial muscle and the peroneal

---

* Corresponding author.
E-mail address: michalinablazkiewicz@gmail.com (B. Michalina).

http://dx.doi.org/10.1016/j.clinbiomech.2016.12.014
0268-0033/

group. Drop foot frequently occurs unilaterally in connection with a stroke leading to hemiplegia. The disorder is characterized by a lack of voluntary control of ankle dorsiflexion and subtalar eversion; the abnormal gait pattern caused by drop foot is characterized by a compensatory movement known as hip hiking. Drop foot constitutes a serious problem for recovering normal gait in patients in combination with other effects of the damage to the central nervous system, e.g. general balance impairment and muscle weakness (Voigt and Sinkjaer, 2000). However, this steppage gait cannot reflect the complex interactions between muscle deficit, structural alterations, biomechanical dysfunctions and compensatory adjustments occurring during the course of the disease. In addition, alongside drop foot, patients affected by gait disorders may also experience plantar flexor deficit, which could further affect their gait (Vinci and Perelli, 2002). These patients have to compensate for the deficiency of the reconstructed joint by using muscles around adjacent or contra lateral joints during walking. Such compensation can be quantitatively evaluated by analyzing temporal parameters, as well as gait kinematics (e.g. angular movement in the joint), kinetics (e.g. ground reaction forces and joint torque), and energy (e.g. joint power).

1.3. Spatiotemporal and kinematic parameters

Few of the existing reports in the literature go beyond providing a clinical and qualitative description of drop foot gait e.g. (Hirahara et al., 2014; Janssens and Vandenberghe, 2010; Sabir and Lyttle, 1984). However, drop foot is the most widely reported clinical feature in Charcot-Marie-Tooth (CMT) patients (Adams and Victor, 1989; Dyck et al., 1993; Han et al., 2015; Vinci, 2001). In the study conducted by Kuruvilla et al. (2000), the number of CMT patients with drop foot was very small, diagnosed based exclusively on clinical criteria, with individually described kinematic and kinetic data and data on clinical features not being provided. More recently, Newman et al. (2007) found several kinematic abnormalities in the gait of a CMT sample. They did not find any overall gait strategy that achieved statistical significance as a compensatory mechanism required to maintain walking ability. For example, neither an increase in hip and knee flexion nor an increase in pelvic obliquity and hip abduction were reported during the swing phase despite the presence of marked drop foot.

1.4. Kinetic parameters

A small number of papers have focused on the analysis of joint torques during drop foot gait (Mallakzadeh and Matinmanesh, 2013; Simonsen et al., 2010), with Simonsen et al. (2010) representing a major work in this field. Given that drop foot disturbs the normal walking pattern severely, these authors hypothesized that the presence of a drop foot would cause a redistribution of net joint torques about the ankle, knee and hip joint, in which case the knee and/or the hip joint could be overloaded probably leading to joint degradation over many years. To the best of our knowledge, no one apart from Voigt and Sinkjaer (2000) has performed a kinetic analysis of drop foot gait. However, in that study the walking parameters were measured only on patients with and without functional electrical stimulation.

Most of the papers analyzing drop foot have described management. Management may include the use of an ankle foot orthosis (Sheffler et al., 2006), functional electrical stimulation (Voigt and Sinkjaer, 2000) or tendon transfer from the posterior tibial muscle (Wagenaar and Louwerens, 2007). However, there appears to have been no study focused on spatiotemporal, kinematics and kinetics parameters in term of the compensation phenomenon. Therefore, the aim of this study was to determine compensation in spatiotemporal, kinematic and kinetic parameters, and to identify the classes of parameters in terms of which these changes were the most evident.

2. Methods

2.1. Participants

The group of patients (DF) consisted of fifteen individuals with unilateral drop foot. Their mean age was 51.4 (17.9) years, height 173.5 (10.3) cm, and body mass 78.8 (18.3) kg. The patients suffered from paresis of the common peroneal nerve caused by lumbar disc hernia (seven patients), mechanical damage and consequently damage to the peripheral nervous system (six patients), and stroke (two patients). In daily life, only two patients used ankle joint orthosis to compensate for the loss of dorsiflexion. In contrast, the control group (C) consisted of fifteen healthy subjects with a mean age of 24.7 (5.9) years, height of 171.6 (9.5) cm and body mass of 71.2 (15) kg. All patients and subjects gave their informed written consent to the experimental procedures, which were approved by the local ethics committee.

2.2. Instrumentation and data collection

First, anthropometric measurements were taken for each person. Next, spherical markers were placed at anatomical landmarks according to the standards of the biomechanical model PlugInGait available within the motion capture system (Vicon Motion Systems Ltd., Oxford, UK). Two force plates, (Kistler Holding AG, Winterthur, Switzerland), embedded into the floor, were used to determine ground reaction force (GRF) data at a sampling rate of 1000 Hz. A motion capture system, consisting of eight infra-red cameras, was employed to collect kinematics data at a sampling rate of 100 Hz. The force plates were synchronized to the motion capture system. Both systems were calibrated according to the manufacturers' recommendations before the trials were conducted. Each subject performed three trials at their preferred walking speed along a 10 m walkway. Each patient walked unassisted (i.e. without crutches, walkers and/or stimulators). The analysis was carried out based only on attempts performed without any incidental mistakes, with the individual performing the task naturally. For patients with bilateral drop foot, the analysis included results obtained from the side affected by more significant dysfunction.

2.3. Data reduction

2.3.1. Comparison of spatiotemporal parameters

For both groups, the following parameters were recorded: cadence (steps/min), double support (%), foot off (%), single support (%), step length (m), step time (%), step width (m), stride length (m), stride time (%), and walking speed (m/s). The spatiotemporal parameters for the two groups were compared using non-parametric Mann–Whitney comparison tests. All statistical analysis was performed using Statistica 10.0 (StatSoft Inc., Tulsa, USA), with a significant P-value set at 0.05. One limitation of this research was the small sample of patients. To account for this, we calculated the statistical power for all significant parameters detected in this study and found an average power of between 85% and 100% using an alpha error level of 5%. This power analysis indicated that the number of patients was adequate to detect a difference, if one existed.

2.3.2. Differences between continuous curves

In order to verify whether the gait cycle curves of angle movement and torque in the lower limb joints in the sagittal plane differ between the C and DF groups, we used the model of independent method of variance and similarity factors (Milanowski, 2009). This method can only be used provided that the variance between individual time points is not too great; that is, the variance factor should be no higher than 15%. The method calculates the values for