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Original Research Article

Quantification of gait asymmetry in patients with ankle foot orthoses based on hip–hip cyclograms

Patrik Kutilek [a], *Vladimir Socha* [a,*], *Slavka Viteckova* [a], *Zdenek Svoboda* [b]

[a] *Faculty of Biomedical Engineering, Czech Technical University in Prague, Prague, Czech Republic*
[b] *Faculty of Physical Culture, Palacky University of Olomouc, Olomouc, Czech Republic*

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ABSTRACT

Our work focuses on a new approach of studying asymmetry in walking based on the orientation of the synchronized bilateral hip–hip cyclograms. Patients with foot drop were included in the study and were asked to walk without an orthosis, and with foot-up splint, calf mounted support strap and ankle wrap. The hip–hip cyclograms were created to quantify gait asymmetry before and immediately after the application of ankle foot orthoses. This approach has never been applied before to study the gait asymmetry in patients with ankle foot orthoses. In order to quantify the gait asymmetry, we have tested the application of the approach based on the inclination angle of the synchronized hip–hip cyclograms. The symmetry index was used as a comparative method to evaluate the symmetry of bipedal walking. The results indicate the correlation between the symmetry index and inclination angle of the synchronized hip–hip cyclograms. The methods based on the inclination angle and symmetry index show slightly different results because the symmetry index depends on discrete variables and is unable to reflect the asymmetry as it evolves over a complete gait cycle. The inclination angle of the hip–hip cyclogram depends on the complete gait cycle. Except for the inclination angles of patients with the support strap, the results show that the new approach did not identify significant improvement in the gait symmetry after the application of the orthoses. The approach based on the orientation of the hip–hip cyclograms can be used as an additional approach for determining the gait asymmetry.

1. Introduction

Several methods can be used for the identification of defects in bipedal walking as a result of pathology of the musculoskeletal or nervous system. A widely used technique for studying gait in clinical practice is gait phase analysis [1,2]. For the study of gait, we used a method based on gait angles analysis using cyclograms (also called angle–angle diagrams or cyclokinograms), because a cyclic process such as walking is better understood when studied with a cyclic plot [3]. Also, the creation of cyclograms is based on body angles during gait that

* *Corresponding author at*: Faculty of Biomedical Engineering, Department of Natural Sciences, Czech Technical University in Prague, nám. Sítná 3105, 272 01 Kladno, Czech Republic.
E-mail addresses: ing.vladimir.socha@gmail.com, oxoid@seznam.cz (V. Socha).

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are well suited for further analysis [4–7]. The aim of this article is to present and test a new approach based on the orientation of the hip–hip cyclograms for the evaluation of the gait.

The gait symmetry can be affected negatively by various factors, and symmetry of joint angle evolutions is an important indicator of proper walking technique. At present, algebraic indices and statistical variables represent two major classes of symmetry quantifiers [8–10]. Algebraic indices include the symmetry index and the ratio index, which compare bilateral variables such as the maximum joint angles. These variables depend on discrete quantities and fail to reflect the asymmetry as it evolves over a complete gait cycle. Statistical methods such as paired *t*-test or PCA, and variables such as correlation coefficients or variance ratio have been also used to quantify the symmetry of variables [8,11]. These variables do not suffer from the limitations of the algebraic indices, but their computation is more complex and interpretation is less clear.

In 2003, Goswami introduced a technique based on the geometric properties of symmetric bilateral cyclograms. The cyclograms are closed trajectories generated by simultaneously plotting two joint variables. In this study, the synchronized bilateral cyclogram which represents the hip joint angles of two sides of a body is used. Thus, the approach is based on the symmetry of hip joint angle evolutions [8,12]. For an absolutely symmetrical angle evolution of the hip joint angles, the area within the curve is zero and its orientation is forty-five degrees [8,13,14].

In this article, we will describe the application of the approach based on the orientation (i.e. inclination) of the hip–hip cyclogram to analyze the gait of patients with peroneal nerve palsy [15] and three types of ankle-foot orthosis (AFO). Peroneal nerve palsy is common entrapment mononeuropathy in the lower extremity. Patients usually present with a foot drop. Foot drop is the name for dorsiflexion weakness of the foot [16]. To dorsiflex the foot while walking, orthopedic devices, i.e. orthoses, are developed in a variety of ways. These devices may include braces, splints, figure-eight elastic straps, and other means [17]. In the case of the use of orthosis for dorsiflexion, the ankle angle is directly affected by the brace, and the knee angle can also be affected by structural elements of some orthosis [18]. It is not appropriate to measure the ankle angle and knee angle which are predetermined by the structural elements of the prostheses. Gait asymmetry cannot be minimalized to the diseased lower extremity parts. Information about the predetermined angles has a little significance in the rehabilitation process. Much more important is the information on the behavior of body segments or joint angles that are not directly affected by the structural elements of the brace but are the result of the indirect effects of the brace. With respect to possible scientific findings and research focus on the study of walking, it is possible to study the hip angles. Thus, hip angles are appropriate to study the gait symmetry. However, cyclograms for the evaluation of the hip joint angles after application of orthoses have never been used before. For these reasons, the application of approach based on the cyclogram orientation (i.e. inclination) by using measured hip joint angles will be tested. The approach based on the orientation of the hip–hip cyclograms can be used as an additional approach for determining the asymmetry of walking of patients with peroneal nerve palsy and/or AFOs.

2. Subjects and methods

2.1. Subjects

The set of data to create and study bilateral hip–hip cyclograms was measured on nine volunteers/patients (age of 46 ± 15 years) with peroneal nerve palsy. These were patients of the Rehabilitation Center Kladruby (Kladruby u Vlasimi, Czech Republic). Patients were selected based on their consent, with no preference whatsoever. All patients were characterized by the presence of a foot drop, and were qualified for a rehabilitation stay at the clinic and selection of appropriate AFO. All patients were measured at the beginning of the rehabilitation stay.

2.2. Motion capture equipment

The camera system with active markers, including two Lukotronic AS 200 (Lutz Mechatronic Technology e.U.) camera units and one control computer with GaitLab software (Lutz Mechatronic Technology e.U.), was used for measuring movements in 3D space [19–21]. The camera units were positioned and calibrated with optical axes perpendicular to each other and placed before the patients walked on a treadmill. The active markers were placed on the following anatomical points: malleolus lateralis, epicondylus lateralis, trochanter major and spina iliaca anterior superior (Fig. 1). The markers were placed in accordance with the recommendation of the MoCap system manufacturer. The GaitLab and MatLab Simulink (The MathWorks Inc.) software was used to identify the joint angles of the lower limbs [13,22,23], and the kinematics model (in the GaitLab and MatLab Simulink) is used for graphical presentation and further processing in the MatLab software (i.e. creation of 2D diagrams, identification of the forefoot/foot flat-touchdown, etc.). Using this method, we can record and study the movement in 3D space, though we primarily study the movement in a 2D sagittal plane. The MOCap system was calibrated accurately before the experiments, and the origin of the world coordinate system was set up so that the first axis is along the track of the treadmill and the other two axes are perpendicular to the track of the treadmill.

2.3. Orthotic equipment

Patients were asked to walk without an orthosis, and with AFOs: foot-up splint, calf mounted support strap and ankle wrap. The foot-up splint (Össur h.f. of Reykjavik, Iceland) is a lightweight non-plastic AFOs designed to provide support for drop foot. The foot-up splint combines two separate parts: an ergonomic ankle wrap/cuff, which connects to a plastic inlay (or strap) that fits between the tongue and the laces of a shoe. The calf mounted support strap, type 702 (long) (SANOMED s.r.o. of Brno, Czech Rebublic), is a lightweight plantar fasciitis splint. The support strap combines two separate parts; an ergonomic calf wrap, which as well connects to a plastic inlay (or strap) that fits between the tongue and the laces of a shoe. The ankle wrap, ProCare DS Ankle Wrap (DonJoy Inc. of Vista, USA), is low profile elastic contact closure figure-eight strap