Gait & Posture 62 (2018) 124–131

Contents lists available at ScienceDirect

Gait & Posture

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

Full length article

Intersegmental kinematics coordination in unilateral peripheral and central origin: Effect on gait mechanism?

Laura Wallard[a,*], Sophie Boulet[a], Olivier Cornu[a,b], Jean-Emile Dubuc[a,b], Philippe Mahaudens[a], Didier Postlethwaite[c], Maïté Van Cauter[b], Christine Detrembleur[a]

[a] Université catholique de Louvain, Secteur des Sciences de la Santé, Institut de Recherche Expérimentale et Clinique, Neuro Musculo Skeletal Lab (NMSK), Avenue Mounier 53, B-1200 Brussels, Belgium

[b] Cliniques universitaires Saint-Luc, Service d'orthopédie et de traumatologie de l'appareil locomoteur, Avenue Hippocrate 10, B-1200 Brussels, Belgium

[c] Cliniques de l'Europe, Service d'orthopédie et de traumatologie, Sainte Elisabeth, Avenue De Fré 206, 1180 Bruxelles, Belgium

ARTICLE INFO

Keywords:
Hip osteoarthritis
Gait analysis
Biomechanics
Intersegmental coordination
Gait control

ABSTRACT

Background: The gait mechanism requires an efficient intersegmental coordination in order to ensure the displacement of the body while simultaneously maintaining the postural stability. However, intersegmental coordination may be disrupted by neurological or orthopaedic involvement, this increasing the metabolic cost associated with excessive or prolonged muscle co-contraction.
Research question: Our aim was to evaluate and to understand how hip OA affects lower limbs coordination during gait by using the kinematic segmental covariation law method and predict the energy expenditure.
Methods: In order to evaluate the influence of unilateral alteration of the lower limbs on the gait mechanism, three groups namely 63 hip osteoarthritis patients, 65 chronic hemiparetic stroke patients and 72 healthy subjects performed an instrumented gait analysis. The subjects had to walk barefoot for at least 3 min at a self-selected speed on a force measuring motor-driven treadmill. The biomechanical variables (kinematic, kinetic and energetical cost) were simultaneously recorded.
Results: The comparison between the three groups was tested using a repeated measure ANOVA. All biomechanical parameters show significant differences between the 3 groups highlighting the gait alteration for the patients groups. However, the energetic cost remains normal in the hip osteoarthritis group despite of the alteration of the other variables. A multivariate analysis allowed to identify the independent variables affecting more specifically their gait mechanisms.
Significance: This study showed the importance of quantitative functional evaluation in order to better understand the impact of hip osteoarthritis on the gait mechanism. The biomechanical analysis provides objective evidence of the altered gait mechanism and more particularly of the intersegmental coordination in these patients. This gait analysis is therefore an interesting tool in the functional evaluation of the patient to better guide the diagnosis.

1. Introduction

Gait disorders can be classified in terms of the hierarchy of lowest, middle, and highest sensorimotor levels. Lowest-level gait disorders include musculoskeletal or primary muscle diseases, peripheral neuropathies or radiculopathies. Middle-level gait disorders include spastic gaits due to hemiparesis or paraparesis, cerebellar syndromes, and parkinsonian gaits. Finally, highest-level gait disorders include gait difficulties due to damage to cerebral hemispheres or psychogenic problems such as cautious gait, subcortical disequilibrium, and frontal gait. The quantitative assessment of this latter level is quite complex given the presence of extrinsic (attention, understanding, behavior) and intrinsic (impaired balance, gait ignition failure, freezing, shuffling) gait factors. The two firsts levels also show various disturbances of the human gait mechanism and are usually assessed in clinical gait laboratories [1]. The alteration of the gait mechanism results from interaction changes between the neurological system and the mechanical demands of the locomotor task.

The gait mechanism requires a correct intersegmental coordination in order to ensure the efficient displacement of the whole body while simultaneously maintaining the postural stability and limiting energetic expenditure [2–4]. Therefore, the intersegmental coordination involves

* Corresponding author.
E-mail address: laura.wallard@uclouvain.be (L. Wallard).

https://doi.org/10.1016/j.gaitpost.2018.03.014
Received 14 August 2017; Received in revised form 15 February 2018; Accepted 6 March 2018

synergetic activation of a large number of muscles to control simultaneously the postural stability and the dynamic equilibrium [5]. However, intersegmental coordination may be disrupted by neurological or orthopaedic involvement, this increasing the metabolic cost associated with excessive or prolonged muscle co-contraction [6,7]. The analyse of intersegmental coordination presents an useful clinical tool to better understand how pathology can affect the muscle strategies during gait [8]. Otherwise, to resolve this complex activation, some authors such as Grillner [9] have shown that the central nervous system uses a hierarchical and synchronized organization of the motor control during gait. The cyclic, rhythmic and alternating movements of the gait are thus generated and controlled by central pattern generators (CPG) that are located to a large extent within the spinal cord, but are under the continuous influence of central signals. This approach hypothesizes that synergetic muscle activation of each lower limbs are controlled by these CPG and that the locomotion would result from the coupled activity of these CPG reflecting intersegmental lower limbs kinematic coordination. From this point of view, other authors [10–13] proposed an original approach of human gait, studying the kinematic segmental coordination of lower limbs by the calculation of angles of these segments (thigh, shank and foot) relative to the vertical and to the forward gait direction. This approach based on kinematic segmental covariation (KSC) law, seems to reflect in part the gait control (lower limb coordination) by CPG [10]. Lacquaniti et al. [12] postulated that planar covariation of limb segments might simplify the control of posture and locomotion by reducing the effective degrees of freedom of muscle activation. Moreover, Bianchi et al. [14] concluded that this planar covariation is a reliable predictor of the mechanical energy expenditure and could be used by the nervous system for limiting the overall energy expenditure. The KSC law's application has been mainly studied in middle-level of gait disorder more specifically in central nervous system diseases such as in chronic hemiplegic stroke patients, (e.g. [15–17]) but much more rare in lowest-level gait disorders as in patients with joint disorders [18,19]. These studies allowed to show that subjects modify their intersegmental coordination in order to compensate weakness of the affected limb, using different muscular synergies compared to asymptomatic subjects. However, does unilateral peripheral (articular) involvement has the same gait control characteristics as unilateral central (neurological) involvement?.

The aim of the present study was to evaluate how severe hip OA affects lower limbs coordination during gait by using the KSC law method and predict the energy expenditure. Due to the severe hip OA, we expected that patients would demonstrate different coordination patterns with changes in the intersegmental coordination observed both in the affected limb but also in the non-affected limb in order to optimize energetic consumption.

2. Methods

2.1. Participants

In order to evaluate the influence of the severe hip OA on the gait mechanisms and in particular on the coordination of the lower limbs during gait by using the KSC law method, we decided to compare the data of these patients (OA group) with the data of patients with also unilateral alteration of the lower limbs namely chronic hemiplegic stroke patients (hemiplegic group).

The recruitment for OA group was performed by using the list of patients (n = 213) consulting for severe OA at the department of orthopaedic surgery and traumatology of the Brussels Cliniques Universitaires Saint-Luc and Brussels Cliniques de l'Europe – Saint Elisabeth in Belgium between January 2016 and January 2017. The patients older than 45 years were invited by phone. After receiving a detailed explanation of the content and objectives of the study, they were given the possibility to participate on a voluntary basis and an appointment was scheduled to obtain written consent and perform the experimentation. All OA patients, included in this study (n = 63, aged 59–75 years old), were diagnosed by 4 board-certified orthopedic surgeons (OC, JED, DP, MVC) with severe hip OA in the grade IV – end-stage as defined by clinical examination and standard radiographic [20], namely classified as severe hip OA. Patients were excluded of hip OA group if unable to ambulate without the use of an assistive device, had pain in more than one lower extremity joint on either limb, had neuro-musculoskeletal diseases, had prior lower extremity joint replacement surgery, had cardio-pulmonary problems or had comprehension problems.

For stroke patients group, we used the gait analysis recordings previously from our outpatient rehabilitation unit between 2000 and 2016. Of our database, we selected 65 chronic hemiplegic stroke patients presenting with spastic hemiparesis which performed an instrumented gait analysis. The inclusion criteria were spastic hemiparesis secondary to stroke, ≥6 months since stroke, ability to walk independently without an assistive device and older than 45 years. The exclusion criteria were inability to walk on a treadmill for sufficient time to complete a metabolic analysis (> 2 min) and troubles of comprehension.

We used the lab norm to compute reference values in 72 healthy subjects, older than 45 years who were asked to perform an instrumented gait analysis. The neurological patients and healthy subjects were selected in order to perform homogenous groups in terms of age, height, weight and gait speed compared to OA patients. The anthropometrics data of each group are summarized in Table 1.

The study was approved by the local ethics committee (B403201523492), and all orthopaedic patients gave written informed consent prior to participation. For neurological and healthy subjects, we used retrospective data not requiring written consent in this case.

2.2. Instrumented gait analysis

In order to study gait, a three-dimensional gait analysis (3DGA) assessment was performed. Each subject was equipped with 19 reflective markers located on specific anatomical landmarks [21]. The subjects had to walk barefoot for at least 3 min at a self-selected speed on a force measuring motor-driven treadmill (Mercury LTmed, HP Cosmos, Germany). A motion capture system with eight infrared cameras (Elite, BTSbioengineering, Italy) measured, at a sampling rate of 200 Hz, the three-dimensional coordinates of reflective markers. Kinematic and kinetic data were simultaneously recorded for 40 s and averaged on 10 successive strides. The gait analysis methods were similar for the three groups.

From kinematics data, we computed cadence and step length parameters. On each angular displacement curve in sagittal plane (pelvis, hip, knee and ankle), we measured the range of motion, defined as peak-to-peak amplitude. The total muscular mechanical work (Wtot) was also assessed. It corresponds to the sum of the external work (Wext), *i.e.* the work performed by the muscles to move the center of body mass relative to the surroundings, and the internal work (Wint), *i.e.* the work performed by the muscles to move the body segments relatively to the center of body mass [22]. The external work was computed from strain gauges measuring 3D-ground reaction forces according to Cavagna [23]. The internal work was computed from

Table 1
Anthropometric characteristics of the three groups.

	Hip OA patients N = 63	Hemiplegic patients N = 65	Healthy Subjects N = 72	*p-value*
Age (years)	65 [59–75]	59 [56–68.5]	61.6 [50–78.4]	0.071
Weight (kg)	75 [66–85]	76 [64.75–87]	73.8 [63–84]	0.70
Height (m)	1.68 ± 0.08	1.7 ± 0.08	1.69 ± 0.09	0.29
Speed (km h^{-1})	2.5 [1.8–3.5]	2 [1.7–2.5]	2.5 [1.25–3.75]	0.085