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Dynamic joint stiffness of the ankle in healthy and rheumatoid arthritis post-menopausal women

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A R T I C L E I N F O

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A B S T R A C T

The purpose of this study was to compare rheumatoid arthritis post-menopausal women (RAPW) with pathological involvement of the lower limb joints and age-matched healthy post-menopausal women (AHPW) in regard to the dynamic joint stiffness of the ankle (DJS_{ankle}) during the stance phase of gait. Data were collected from 18 RAPW and 18 AHPW. Gait was assessed by a three-dimensional motion analysis system synchronised with a force plate. Subjects walked barefoot at natural and self-selected speed, performing 14 valid trials (comprising 7 left and 7 right foot-steps on a force plate). The stance phase was split into three sub-phases that corresponded to the three angular displacements of the ankle that occurred during this phase, namely, controlled plantar flexion (CPF), controlled dorsiflexion (CDF), and powered plantar flexion (PPF). A linear model represented each sub-phase and computed DJS_{ankle}. Model fitting was assessed by the coefficient of determination (R^2). The coefficient of variation (CV) was used to assess intra-individual variability. In all sub-phases, R^2 values for both groups were higher than 0.85. There were no differences in the R^2 values among groups. RAPW showed a higher DJS_{ankle} during the CPF ($p < 0.05$). CDF and PPF yielded no differences among groups. During CPF, RAPW yielded a higher CV for DJS_{ankle} ($p < 0.01$). RAPW also yielded lower ankle angular displacements during CPF and PPF ($p < 0.05$). Findings suggested that the stance phase of RAPW and AHPW can be studied by a linear ankle 'moment of force –– angle' relationship. During CPF, RAPW exhibited excessive ankle stiffness and presented a higher intra-individual DJS_{ankle} variability.

1. Introduction

Rheumatoid arthritis is a chronic systemic disease that affects joints, connective and fibrous tissue, muscles, and tendons [1]. Women are more susceptible to the development of rheumatoid arthritis [2], and the peak age for the onset of the disease is between the fourth and the sixth decades of life [3], establishing rheumatoid arthritis post-menopausal women (RAPW) as the greater percentage of patients. Cachexia has also been observed in rheumatoid arthritis patients [4] with consequent signs of muscle strength reduction [5], and a reduction in functional capacity [6]. Otherwise, the decrease in the level of estrogens owing to menopause play a potential role in the decrease of muscle mass and function after the fifth decade of life [7].

Changes that occur in rheumatoid arthritis (muscle mass reduction, joint pain, joint destruction) and during the menopausal process (muscle mass reduction) could modify the visco-elasticity of the structural biological joint components during muscular activities. Modification of the viscoelastic properties can influence force transmission, spinal reflex responses, and the way that movement accuracy and joint position are controlled [8]. This modification could lead to alterations in joint stability. Proprioception and stiffness play an important role in establishing this stability [9]. While some stiffness is necessary, too much or too little it not advisable, and may lead to injuries [10]. The optimal stiffness is adjusted to the movement́s objectives, ensuring the stability of the joint.

One way of assessing and studying joint stiffness is through the so-called dynamic joint stiffness, which was defined as the resistance developed by muscles and other joint structures during inter-segmental displacement, as a reaction to an external moment of force [11]. Two components are involved, the passive and the active. Passive components are related to the state and characteristics of the joint structures (bones, muscles, tendons, ligaments). Active components are related to

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Table 1
Clinical and demographic data.

Variables	RAPW (n = 18) Mean (SD)	AHPW (n = 18) Mean (SD)	P value
Age (years)	64.3 (8.4)	64.3 (7.8)	1.000
Disease duration (years)	11.5 (10.7)	–	–
DAS-28 score	4.4 (1.2)	–	–
Duration of menopause (years)	16.9 (8.7)	15.0 (9.1)	0.530
Body mass (kg)	63.7 (9.8)	64.5 (12.6)	0.826
Height (m)	1.52 (0.06)	1.54 (0.06)	0.301
Body mass index (kg/m^2)	27.8 (4.8)	27.2 (4.6)	0.705
	Lower limbs (n = 36) Frequencies (%)	Lower limbs (n = 36) Frequencies (%)	
Hips with pathological involvement	1 (2.8)	–	
Knees with pathological involvement	12 (33.3)	–	
Ankles with pathological involvement	19 (52.8)	–	
Midtarsal joints with pathological involvement	8 (22.2)	–	
1st MTP joints with pathological involvement	15 (41.7)	–	
Other MTP joints with pathological involvement	15 (41.7)	–	
IP joints with pathological involvement	6 (16.7)	–	
PIP joints with pathological involvement	7 (16.7)	–	
Feet with their joints* with pathological involvement	23 (63.9)	–	

AHPW – age-matched healthy post-menopausal women; DAS-28 score – Disease Activity Score (28 joints); IP – interphalangeal; MTP – metatarsophalangeal; PIP – proximal interphalangeal; RAPW – rheumatoid arthritis post-menopausal women; SD – standard deviation; *(midtarsal joint; metatarsophalangeal joints; interphalangeal joints; proximal interphalangeal joints).

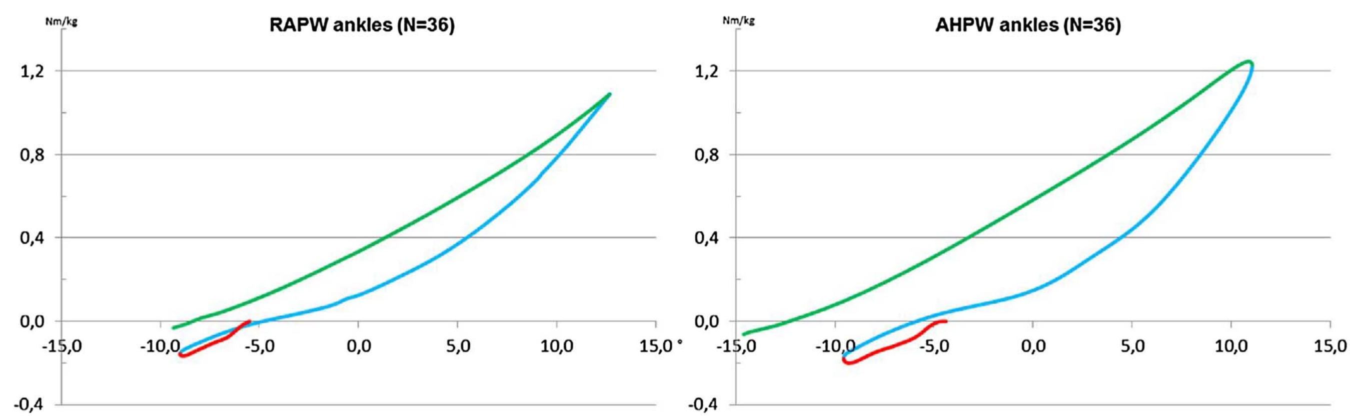

Fig. 1. Ankle moment of force plotted as function of the ankle angle in the sagittal plane during the gait stance phase (left graphs for the rheumatoid arthritis postmenopausal women; right graphs for the age-matched healthy postmenopausal women). Gait stance phase split into three sub-phases: controlled plantar flexion (red); controlled dorsiflexion (blue); powered plantar flexion (green). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

muscular activity, and are therefore dependent on the adaptive and neuromuscular capacities. Moments and angles change in accordance to stride phases [12], and joint stability can be interpreted as the performer‘s ability to maintain an appropriate joint angle position during activation of motor pathways [13]. Quantitatively, dynamic joint stiffness is represented by the slope of the joint moment of force plotted as function of the joint angle: $S = dM/d\theta$ (M – joint moment of force; θ – joint angle) [11,13,14]. Theoretically, the slope can be represented by a linear model, and could be representative of dynamic joint stiffness. However, linear models do not take into account the viscosity inherent to the active and passive components. Coefficient of determination (R^2) is a quantitative index that denotes how well data fit to a linear model, and in the present case it could represent the percentage of the joint’s elastic behaviour, in a manner similar to that recorded and analysed in a previous study [13], whereby $R^2 > 0.8$ were considered to be very close to a linear behaviour during ankle dorsiflexion and plantar flexion in the stance phase of gait.

During the stance phase of gait, the foot executes important functions. Specifically, it controls the impact with the ground, creates a stable support over which the body can advance, and propels the body [15,16]. Previously conducted work [11–14,17–21] studied the ankle ‘moment of force – angle’ relationship during the stance phase of gait as a valuable analysis tool, and as a demonstration of the interaction of kinematics and kinetics [20]. These studies found that this interaction in the sagittal plane reveals a considerable loop-shaped curve that can be represented using linear models. Adhering to diverse criteria, these studies split the ‘moment of force – angle’ curve into sub-phases and verified different characteristics by defining quasi-linear behaviours for each sub-phase. The adjustment of the model was represented by a high R^2 value. Some of these authors [18,19,21] split the ‘moment of force – angle’ curve into the three expected angular displacements of the ankle during the stance phase, namely, into plantar flexion, dorsiflexion, and plantar flexion. These three angular displacements of the ankle are associated with movement objectives that correspond to the aforementioned three functions of the foot during the stance phase, i.e. the control exerted by the foot upon impact with the ground, the establishment of a stable support, and the propulsion of the body. These authors split the ‘moment of force – angle’ curve into the controlled plantar flexion (CPF), the controlled dorsiflexion (CDF), and the powered plantar flexion (PPF). Specifically, CPF begins at the heel strike and ends at the instant of occurrence of maximum plantar flexion, CDF begins at the end of the CPF and ends at the instant of occurrence of