

KINETIC AND KINEMATIC GAIT ASSESSMENT OF PARAPLEGIC PATIENTS WITH AND WITHOUT ANKLE FOOT ORTHOSES

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Abstract: Objective: To assess the influence of rigid ankle foot orthoses (AFOs) on paraplegic gait with neuromuscular electrical stimulation (NMES). Methods: Ten control subjects and five complete paraplegics went through kinetics and kinematics gait evaluation without and with AFOs. Paraplegics also used 4 channels NMES, walker aided. Results: Cadence, in steps per minutes (94.6/6.8; 84.97/13.15; 13.02/4.11; 16.1/2.29), step length, in meters (1.31/0.15; 1.19/0.17; 0.55/0.11; 0.6/0.11) and % stance time (61.5/1.8; 62.93/3.37; 87.8/7.26; 89.9/2.6) for controls and paraplegics, without and with AFOs, respectively. Differences are shown for the controls as well as between paraplegic groups. Ankle joints kinematics displayed no significant changes. However, the ankle dorsiflexion, in the support phase, for controls and paraplegics with AFO was higher than expected (10.97/5.67; 15.48/8.08). Kinetic values were: maximum hip extensor moments (Nm/kg) of 1.84/0.48; 3.36/5.79; 1.45/0.59; 1.58/0.41 and maximum knee extensor moments of 3.53/0.52; 3.04/0.87; 1.44/1.37; 1.24/0.78. Conclusion: Within the paraplegic groups, through spatiotemporal results, gait with AFO was more effective. Nevertheless, the AFO allowed more ankle mobility than expected. Furthermore, lower limb loading, i.e. hip and knee moments generated during NMES+AFO paraplegic gait allows for bone mass increase.

1 INTRODUCTION

The incidence of spinal cord injury varies around the world, but it is usually reported to be between 20 and 50 cases per million per year and approximately half of whom are under 30 years of age (Barbeau et al, 1999).

The main complaint of spinal cord injury individuals is the mobility loss below the lesion and consequently, the inability to walk. For this reason, recent studies are being performed on locomotion after spinal cord injury (Behrman et al, 2000).

These individuals' gait can be restored through the electrical activation of paralyzed or spastic muscles, using neuromuscular electrical stimulation (NMES) (Behrman et al, 2000). This gait seeks to

minimize the general physiological effects resulting from spinal cord lesions, i.e., osteoporosis, muscle atrophy, cardiovascular deficiencies, spasticity, repetitive urinary infections, and others (Carvalho et al, 2005; Carvalho et al, 2006; Sepulveda, 1997).

Auxiliary devices are also used during such gait, like walkers and orthoses, mainly rigid ankle foot orthoses (AFO), which restrict the ankle's mobility, keeping the foot in dorsiflexion and avoiding ankle fractures; furthermore it does not allow the tibia's bearing on the foot during the stance, reduce the equinus, thus improving the body weight support during the stance and pre-balance phases. Besides the effects on foot and ankle, the rigid AFO also provides different effects on the proximal joints during the gait (Abel et al, 1998).

Therefore, it becomes rather important to analyze the AFO's effects on the paraplegic gait, in order to understand the differences generated by its use, towards producing a more functional gait for these patients.

2 METHODS

Ten healthy control subjects and five complete paraplegics, with lesions over one year old (all male and aged between 20 and 40 years) were recruited. The work was approved by the local Ethics Committee.

All individuals went through kinetics and kinematics gait evaluation at The Biomechanics and Rehabilitation Laboratory of the UNICAMP Clinical Hospital. For this assessment a six meter long versus one meter wide pathway was used, together with a force platform (AMTI, Newton, MA, USA) and six infrared cameras ProReflex (Qualisys), sampling being done at 240Hz. Rigid AFOs, a pair of sandals, ankle protection braces and seven reflective spherical markers placed on a lower limb (between the second and third metatarsal, on lateral malleolus, calcaneus, tibial tuberosity, knee joint line, superior patella and greater trochanter of femur) were also part of the gear.

The paraplegics walked on the pathway placing a foot on the force platform, using four channels of NMES bilaterally (quadriceps muscles and fibular



Figure 1: Paraplegic gait with AFOs + NMES, sandals and reflective spherical markers.

nerve) and walker aided in two different situations. First with rigid AFOs and sandals (figure 1), after this, just with sandals and ankle braces.

The control group also walked on the pathway, placing the right foot on the force platform, first walking using only the sandals and after that, sandals with the rigid AFOs. As soon as they put on the orthoses the subjects walked for some minutes to get used to the AFOs.

All situations were performed three times on the same day and the averages were taken for analysis.

Parameters analyzed were cadence, step length, percentage of stance, ankle, knee and hip angles and also moments on these joints.

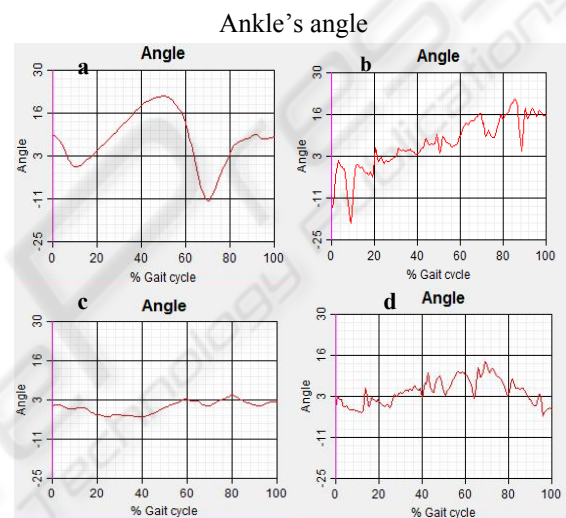


Figure 2: Typical kinematic data of ankle: a) Controls without AFOs, b) Paraplegics without AFO, c) Controls with AFOs, d) Paraplegics with AFOs.

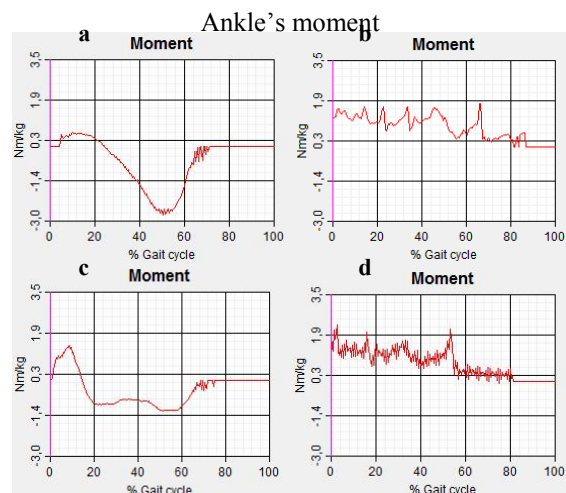


Figure 3: Typical kinetic data of ankle: a) Controls without AFOs, b) Paraplegics without AFO, c) Controls with AFOs, d) Paraplegics with AFOs.

Table 2: Kinematic data.

Variables	Control	Control	Paraplegic	Paraplegic
	without AFO	with AFO	without AFO	with AFO
	Mean / SD	Mean / SD	Mean / SD	Mean / SD
Ankle initial contact (°)	3,6 / 4,78	4,55 / 4,54	-2,33/3,05* ⁺	0,25 / 6,22
Ankle's ROM in stance (°)	15,86/5,76	6,28/1,55	19,72/10,5 ⁺	14,82/7,51 ⁺
Ankle's ROM in balance (°)	15,00/4,92	5,27/1,73	14,93/10,04 ⁺	12,68/11,82
Knee's initial contact (°)	-0,69 / 5,4	4,51/6,3	1,95/8,0	3,27/6,45
Knee's flexion at toe-off (°)	35,10/5,5	32,63/4,9	13,73/9,5* ⁺	11,13/6,9* ⁺
Maximum knee flexion in balance (°)	64,50/5,8	63,59/7,9	19,17/12,7	14,9/10,6* ⁺
Knee's ROM in stance (°)	28,4/3,00	20,92/4,86	25,05/12,08	15,13/4,61
Hip's initial contact (°)	17,98/4,5	18,35/4,3	4,57/3,6* ⁺	6,2/2,23* ⁺
Maximum hip extension in stance (°)	-13,08/3,9	-14,07/4,0	-18,98/2,2* ⁺	20,76/6,07* ⁺
Hip at toe-off (°)	-8,08/4,7	-7,8/4,8	-15,85/6,0* ⁺	-14,35/5,22* ⁺
Maximum hip flexion in balance (°)	22,59/4,8	23,75/6,8	9,23/8,0* ⁺	12,07/4,65* ⁺
Hip's rotation ROM (°)	19,41/4,48	18,05/4,6	39,94/14,23* ⁺	52,56/29,66* ⁺
Hip's abdu/adu ROM (°)	7,69/2,6	7,42/2,8	12,44/3,4* ⁺	13,31/4,42* ⁺

Abbreviations: SD, standard deviation; Abdu, abduction; Adu, adduction; ROM, Range of motion.

*p<0,05 between controls without AFO and paraplegics, ⁺p<0,05 between controls with AFO and paraplegics.

Figures 2 and 3 show typical data illustrating angles and moment, respectively, about the ankle for controls and paraplegics (NMES) with and without AFOs.

Data analysis was performed using the Mann-Whitney test, using Bioestat 4.0 program to verify the samples variance. The controls were compared with the patients in the two different situations, considering p<0,05 as statistically significant.

3 RESULTS

Individuals in the control group presented a mean age of 23.6 (±2,46) years old, mass of 80,3 (±12,69) kilograms and height of 1,81 (±0,06) meters. For the paraplegic group the mean age was 31,4 (±8,62) years old, mass 80,8 (±14,74) kilograms and height of 1,81 (±0,08) meters.

Table 1: Spatiotemporal variables.

Variables	Control	Control	Paraplegic	Paraplegic
	without AFO	with AFO	without AFO	with AFO
	Mean/SD	Mean/ SD	Mean / SD	Mean/ SD
Cadence (steps/ min)	94.6 / 6.8	84.97 / 13.15	13.02 / 4.11* ⁺	16.1 / 2.29* ⁺
Step length (m)	1.37 / 0.15	1.18 / 0.17	0.55/ 0.11* ⁺	0.6/ 0.11* ⁺
% stance time	61.5 / 0.15	62.93 / 3.37	87.8 / 7.26* ⁺	89.9 / 2.6* ⁺

Abbreviations: SD, standard deviation.

*p<0,05 between controls without AFO and paraplegics,

⁺p<0,05 between controls with AFO and paraplegics

The results of spatiotemporal variables are shown in table1. Table 2 presents kinematic data and figures 4, 5 and 6 flexion-extension range of motion (ROM) of ankle in stance and balance and knee in stance respectively. Figure 7 represents hip rotation ROM. The kinetic results are shown in table 3.

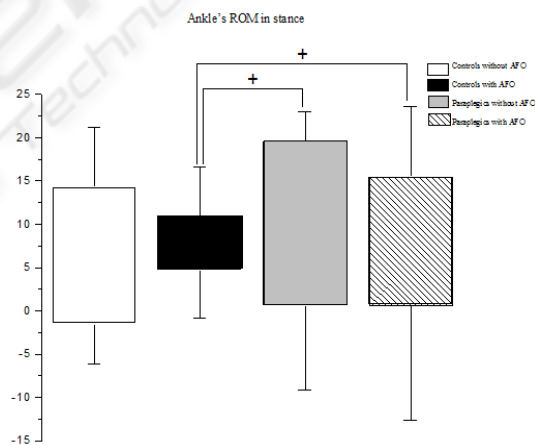


Figure 4: Ankle's ROM in stance for controls without and with AFO and paraplegics without and with AFO. Values are mean and standard deviation (SD). *p<0,05 between controls without AFO and paraplegics, ⁺p<0,05 between controls with AFO and paraplegics.

Table 3: Kinetic data.

Variables	Control without AFO	Control with AFO	Paraplegic without AFO	Paraplegic with AFO
	Mean / SD	Mean / SD	Mean / SD	Mean / SD
Ankle moment at load response (Nm/kg)	-0.01 / 0	0.09 / 0.21	0,42 / 0,37	0,6 / 0,48*
Maximum ankle moment (Nm/kg)	0.74/0.31	0.9/0.51	1.25/0.88	1.4/0.56*
Ankle moment at presswing (Nm/kg)	-0.95/0.58	-0.68/0.28	-0.08/0.93	-0.25/0.85
Maximum knee flexion moment (Nm/kg)	-1.3/0.36	-1.19/0.51	-1.2/0.47	-1.48/0.35
Maximum knee extension moment (Nm/kg)	3.53/0.52	3.04/0.87	1.44/1.37*	1.24/0.78* ⁺
Maximum hip extension moment (Nm/kg)	1.84/0.48	3.36/5.79	1.45/0.59	1.58/0.41
Maximum hip flexion moment (Nm/kg)	-4.65/0.6	-3.82/0.89	-1.6/1.85* ⁺	-1.02/1.1* ⁺
Maximum abduction moment (Nm/kg)	-1.84/0.61	-2.1/0.49	-2.23/0.56	-1.6/0.6

Abbreviations: SD, standard devia

*p<0,05 between controls without AFO and paraplegics, ⁺p<0,05 between controls with AFO and paraplegics.

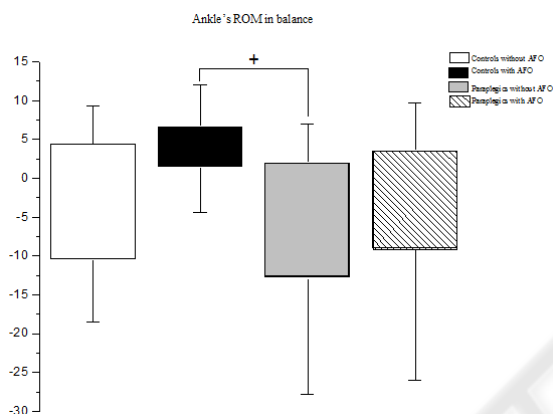


Figure 5: Ankle's ROM in balance for controls without and with AFO and paraplegics without and with AFO. Values are mean and standard deviation (SD). *p<0,05 between controls without AFO and paraplegics, ⁺p<0,05 between controls with AFO and paraplegics.

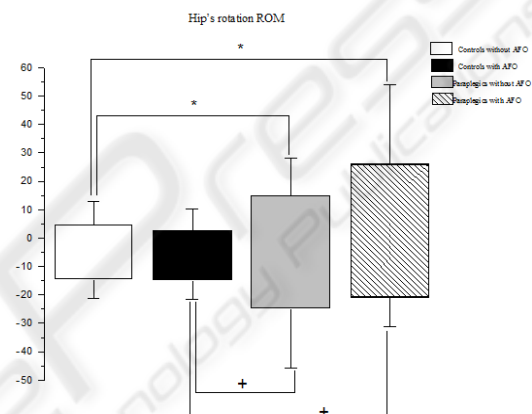


Figure 7: Hip's rotation ROM for controls without and with AFO and paraplegics without and with AFO. Values are mean and standard deviation (SD). *p<0,05 between controls without AFO and paraplegics, ⁺p<0,05 between controls with AFO and paraplegics.

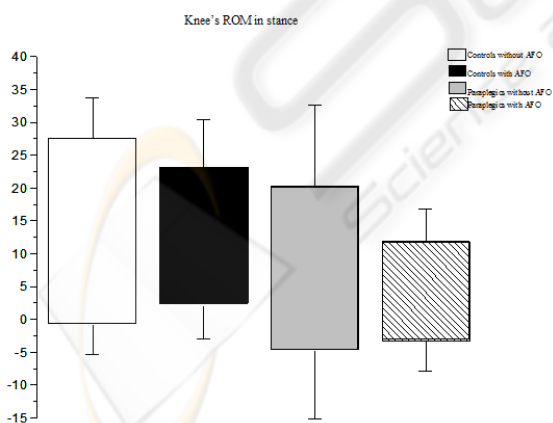


Figure 6: Knee's ROM in stance for controls without and with AFO and paraplegics without and with AFO. Values are mean and standard deviation (SD). *p<0,05 between controls without AFO and paraplegics, ⁺p<0,05 between controls with AFO and paraplegics.

4 DISCUSSION

The ankle joint has important mechanical and neural control roles during gait, its muscles acting to support the body weight and moving the center of mass forward during the final stance and early balance, also reducing the energy loss (Sawicki et al, 2006). However, neurological or orthopedic patients who have equinus foot, make use of rigid AFOs to improve gait, through an increasing speed and better stability during stance phase (Sawicki et al, 2006; Radtka et al, 2006; Kim et al, 2004). In this study, subjects in the control group showed an increase in the stance percentage and a decrease in cadence and step length when using the rigid AFO. In the paraplegic group such decrease was noted when the subjects were not using the orthoses. Kim et al (2004) analyzed gait in 19 incomplete spinal cord injured subjects on four different situations: with

AFO and NMES (on the fibular nerve), with AFO, with NMES and without orthoses, finding that when used together, the AFO and NMES provided better benefits to the patient's gait, such as increasing speed, step length and cadence. NMES acted more during the balance and the AFO in stance by improving the patient's ability to support the body weight during the early stance.

In another study, Sawicki et al (2006) performed a kinematic and electromyographic ankle's assessment of five incomplete spinal cord injury patients during treadmill gait in three different situations, without AFO, with AFO and with pneumatic AFO which promoted plantar flexion during the gait. From that, they observed a better muscle activation, a greater ankle's angle and moment when patients were using the two types of orthoses. Such results were also found in this present study, with complete paraplegics.

Rather relevant in this present work is that dorsiflexion was found higher than expected for the subjects of all groups using the rigid AFO. This may have occurred due to polypropylene material deformation during weight loading / unloading. In another AFO study also a higher ankle dorsiflexion was noted due to the material deformation that occurs even in rigid AFOs type (Behrman et al, 2000).

Kinetics and kinematics compensations in proximal joints were also noted when the groups were using the rigid AFO. Radtka et al (2006) also showed these compensations in healthy subjects using rigid AFO, but their study was in stair locomotion.

Subjects who suffer spinal cord injury present a significant reduction of physical capacity resulting in a dramatic decrease in bone mineral density. Carvalho et al (2006) evaluated the effect of treadmill gait training associated with NMES on bone mass of twenty one tetraplegic subjects and the results showed that the increase in bone formation rate was associated with gait training. This also may happen in paraplegic's gait training.

In the present study, the hip extension moment were higher during the gait with AFO, which means that the AFO provides an increase of the mechanical load on the hip, what can lead to prevent or reverse the bone loss.

5 CONCLUSIONS

The spatiotemporal results suggest that the gait with AFO is more effective for complete paraplegic

individuals. Also, the findings show how restrictions on ankle's joint through AFO can affect not only this joint, but also knee and hip, for compensation of ankle's loss of mobility. Furthermore, the AFO allowed more ankle mobility than expected and the lower limb loading, i.e. hip moments generated during NMES with AFOs paraplegic gait allows for bone mass increase.

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