Effects of rigid ankle foot orthoses on paraplegic gait with neuromuscular electrical stimulation

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Abstract

Objective: To assess the benefits of rigid ankle foot orthoses (AFO) on paraplegic gait with neuromuscular electrical stimulation (NMES). Methods: Ten control subjects and six complete paraplegics went through kinetics and kinematics gait evaluation without and with AFOs. Paraplegics also used 4 channels NMES, walker aided. Results: For ankle joint kinematics, the range of motion (ROM) during stance was significantly different with and without AFO (p=0,01) and between groups (p=0,02). ROM during balance was different with and without AFO (p=0,002). Knee kinematics displayed significant changes with and without AFO in ROM during stance (p=0,0001). For hip significant differences were observed between groups in maximum extension during stance (p=0,002) and in maximum flexion during balance (p=0,001). Ankle joint kinetic variable assessed was the maximum plantar flexor moment, that displayed significant changes between groups (p=0,014). Knee and hip had maximum flexor and extensor moments assessed. Only the maximum knee extensor moment and maximum hip flexor moment were significantly different between groups (p=0,0002 and p<0,0001). Conclusion: Results suggest that gait with AFO is more effective for complete paraplegic individuals. Furthermore, the AFO allowed a greater knee and ankle protection to these individuals and also yielded a higher mechanical loading on the hip, which can prevent the loss of bone mass.

Keywords: *kinetic, kinematic, gait, ankle foot orthoses, paraplegic.*

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[1].

The main complaint of spinal cord injured 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[2].

Such gait can be restored through the electrical activation of paralyzed muscles, using neuromuscular electrical stimulation (NMES)[2]. 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[3,4,5].

Auxiliary devices are also used during such gait, like walkers and orthoses, rigid ankle foot orthoses (AFO) in particular, which restricts the ankle mobility, keeping the foot in dorsiflexion and avoiding ankle fractures; furthermore it does not allow the tibia's bearing on the foot during stance, reduce 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 gait[6].

It therefore becomes rather important to analyze AFOs benefits on the paraplegic gait, in order to understand the differences generated by its use, towards producing a more functional gait.

Material and Methods

Ten healthy control subjects and six 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 at University 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 nerve) and walker aided in two different situations. First with rigid AFOs and sandals, 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 knee and hip angles and moments on these joints.

Data analysis was performed using the ANOVA test. The parameters were compared between groups and with and without AFO, considering p≤0,05 as statistically significant.

Results

Individuals in the control group presented a mean age of 24 (±3,7) years old, mass of 80,3 (±12,7) kilograms and height of 1,8 (±0,1) meters. For the paraplegic group the mean age was 28 (±4,8) years old, mass 75,5 (±15,8) kilograms and height of 1,8 (±0,1) meters.

The kinematic results are shown in table 1. In ankle joint kinematic the range of motion (ROM) in stance was significantly different between groups (p=0,02) and with and without AFO (p=0,01). Ankle's ROM during balance displayed difference only with and without AFO. For the knee the ROM during stance (figure 1) showed significant difference with and without AFO (p=0,0001). The maximum knee flexion during balance was significantly different between groups (p<0,0001). Significant differences for the hip were observed between groups in maximum extension during stance and maximum flexion during balance (p=0,002, p=0,001).

The kinetics results are shown in table 2. For the ankle joint kinetics plantar flexor moment was assessed and that displayed difference between groups (p=0,014). For the knee and hip maximum flexor and extensor moments were assessed. For the knee only maximum knee extensor moment was significantly different between groups (p=0,0002), and for the hip the significant difference was displayed in maximum flexor moment between groups and with and without AFO (p<0,0001, p=0,038).

Table 1: Kinematic data

Variables (degrees)	Control with AFO	Control without AFO	Paraplegic with AFO	Paraplegic without AFO
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD
Ankle ROM in stance	6,28 ±1,55*$^{+}$	15,86 ±5,75*$^{+}$	16,99 ±9,41*$^{+}$	16,07 ±9,91*$^{+}$
Ankle ROM in balance	5,27 ±1,73^{+}	15,01 ±4,93^{+}	19,54 ±20,0^{+}	13,02 ±8,45^{+}
Maximum knee flexion in balance	63,59 ±7,98*	64,48 ±5,98*	17,61 ±11,58*	22,43 ±11,26*
Knee ROM in stance	20,92 ±4,86^{+}	28,39 ±3,01^{+}	17,96 ±3,95^{+}	23,74 ±10,15^{+}
Maximum hip extension in stance	-14,07 ±4,08*	-13,08 ±3,97*	-20,87 ±5,27*	-18,85 ±1,8*
Maximum hip flexion in balance	23,75 ±6,94*	22,59 ±4,79*	11,69 ±5,33*	9,23 ±7,39*

SD, standard deviation; ROM, range of motion.
*p≤0,05 between groups, $^{+}$p≤0,05 with and without AFO.

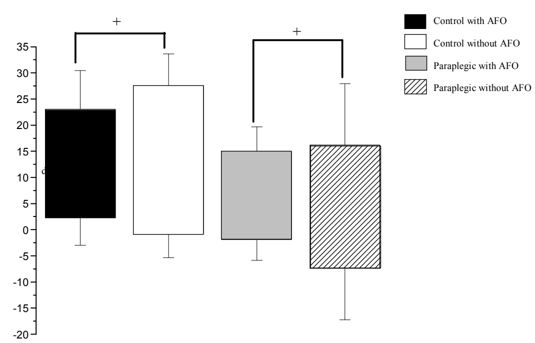

Fig. 1: Knee ROM in stance, with and without AFO +p≤0,05.

Table 2: Kinetic data

Moment (Nm/kg)	Control with AFO	Control without AFO	Paraplegic with AFO	Paraplegic without AFO
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD
Maximum plantar flexion	0,89 ±0,52*	0,75 ±0,33*	1,55 ±0,57*	1,29 ±0,71*
Maximum knee flexion	-1,18 ±0,51	-1,29 ±0,36	-1,62 ±0,34	-1,48 ±0,37
Maximum knee extension	3,04 ±0,88*	3,52 ±0,53*	1,42 ±0,8*	1,37 ±1,07*
Maximum hip flexion	3,81 ±0,89*$^{+}$	-4,64 ±0,59*$^{+}$	-1,34 ±1,19*$^{+}$	-1,59 ±1,41*$^{+}$
Maximum hip extension	1,47 ±0,55	1,84 ±0,47	1,66 ±0,54	1,27 ±0,62

SD, standard deviation.
*p≤0,05 between groups, $^{+}$p≤0,05 with and without AFO.

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[7]. 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[7, 8, 9].

For the ankle, patients showed higher ROM than individuals in the control group, especially when the AFO was used. However, results from control group without AFO were similar to those patients without AFO. Both in balance and stance, when patients used AFOs, ROM were found higher than the six degrees of dorsiflexion and plantarflexion expected. This may have occurred due to polypropylene material deformation during weight loading / unloading. In another AFO study a higher ankle dorsiflexion was also noted due to the material deformation that occurs even in rigid AFO type[2].

For the knee joint, the control group showed a smaller ROM in support when using the AFO, since the AFO did not allow knee extension. In addition, it prevents a higher knee flexion, which could happen due to the limitation imposed by the AFO during anterior tibial bearing support [6].

The ROM during support in the patients group was also higher when these individuals were not using AFO, with values closer to healthy individuals. However, data shows patients having a lower flexion and a higher knee hyperextension during stance. Therefore, the orthoses promote a lower knee hyperextension performing a protection for the joint during stance.

Results of maximum knee flexor and extensor moments also demonstrated that gait with NMES does not bring risks (Charcot joint) to the knees of paraplegic patients[10].

The hip flexor moment was higher in control group and the extensor hip moment did not differ between groups and with and without AFO. However, when the patients were using AFO the maximum extension value, which occurs early in stance, was closer to the control group without AFO. This suggests that the AFO provides an increase of the mechanical load on the hip in paraplegics individuals, what can lead to prevent or reverse bone loss[4].

Conclusion

Results suggest that the gait with AFO is effective for complete paraplegic individuals. Also, the AFO allows more ankle dorsiflexion and plantarflexion than expected and a greater knee protection to these individuals. Furthermore, the AFO yielded a higher mechanical loading on the hip, which can prevent the loss bone mass.

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