Subthalamic Nucleus Stimulation in Parkinson's disease: biomechanical analysis of the gait initiation process

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Abstract

In the present study, the impact of Subthalamic Nucleus stimulation on the gait initiation process of patients with Parkinson's disease is investigated. Ten PD subjects with bilaterally implanted STN stimulation devices have been considered for a multifactorial movement analysis protocol, implying standing upright and gait initiation after a verbal cue. Patients were tested in basal condition, with bilateral and unilateral STNstim. Effects of STNstim on the standing posture included significant normalization of the vertical alignment of the trunk and shank segments, and backward shift of the centre of pressure (CoP). Improvements were higher in bilateral than in unilateral STNstim. Moreover, they were more consistent in the case of standing preceding the gait initiation cue (attentional-demanding condition), as compared to quiet stance. Effects of STNstim on the gait initiation process included shortening of the imbalance phase, larger initial backward/lateral CoP displacement and more physiological expression of the anticipatory postural muscle synergy. Results show that STNstim can produce improvement of the upright standing, especially in attentional-demanding conditions, and restoration of the anticipatory postural actions associated with the initiation of multijoint movements. Our data confirm the effects of STNstim on basic motor control mechanisms, and suggest an action also on structures related to cognitive processing and motor memory.

1. INTRODUCTION

The positive effects of subthalamic nucleus stimulation (STNstim) on walking features of subjects with Parkinson's disease (PD) have been demonstrated both clinically [1] and instrumentally [2]. In particular, steady-state walking has been studied on treadmill and overground, with improvements reported on gait parameters, trunk kinematics, joint kinematics and joint dynamics. The effects of STN stimulation on body sway during quite standing have been studied too [3]. On the contrary, less attention have been devoted to the transitional locomotor phases, which are known to be consistently impaired in PD patients [4]. In the present study, we sought to study the effects of STN stimulation on the anticipatory postural adjustments involved in the initiation of gait, by a detailed kinematic and kinetic analysis on a group of PD patients previously implanted with STN stimulation devices.

2. METHODS

2.1. Subjects

Ten idiopathic PD patients (five males and five females) with a mean age of 60.2 years (range 56-68 years) and ten sex/age-matched controls voluntarily took part in the study. All had given written informed consent and the protocol had been approved by the local Ethical Committee. The PD patients had been implanted bilaterally in the Subthalamic Nucleus. At the time of the study, the mean amplitude of the stimulation was 3.1 ± 0.4 V, the mean frequency was 143.3 ± 17.4 Hz and the pulse width was 60 μs in 60% of the electrodes and 90 μs in the remaining 40%.

2.2. Data acquisition and processing

Standing still upright posture and gait initiation in response of a verbal cue were studied by means of a multifactorial analysis including kinematics and dynamics.

The kinematic analysis was performed following the procedure described in [5]. In particular, an optoelctronic system (ELITE, BTS, Milan, Italy) was used, consisting of four video cameras working at a sampling rate of 50 Hz and positioned on both side of the subject.

The working volume was 2.5 × 1 × 2 m^3. A set of 10 mm retro-reflective markers were glued on bony landmarks belonging to lower limbs, pelvis and trunk.

After the acquisition, marker coordinates were low-pass filtered with a cut-off frequency of 3-7 Hz. Anthropometric parameters of each subjects were measured and used to estimate internal joint centers. Hence, lower limb and trunk kinematics were computed. As for the dynamic analysis, ground reaction forces and COP (Centre Of Pressure) coordinates were measured by a KISTLER force platform (sampling rate of 50 Hz) embedded in the floor within the working volume. This signals were used for the calculation of COP trajectory and mechanical moment at lower limb joints.

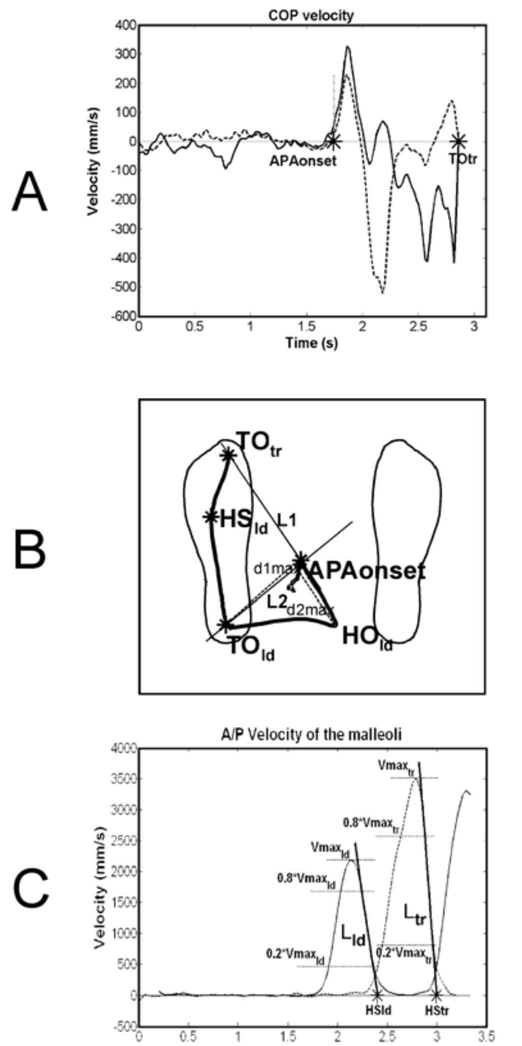

Fig. 1 – Definition of temporal markers: A) A/P and M/L components of COP velocity, B) COP trajectory, C) velocity of the malleoli of leading (solid line) and trailing foot (dashed line).

Six temporal markers describing the gait initiation process were automatically computed (see Fig.1): 1) onset of the anticipatory postural adjustment phase (APA onset); 2) heel-off of the leading foot (the foot which performs the first step) (HO_{ld}); 3) toe-off of the leading foot (TO_{ld}); 4) heel-strike of the leading foot (HS_{ld}); 5) toe-off of the trailing foot (TO_{tr}) and 6) heel-strike of the trailing foot (HS_{tr}). Fig.1B shows the main phases of the gait initiation process: imbalance phase (between APAonset and HO_{ld}), unloading phase (HO_{ld} - TO_{ld}) and first swing phase (TO_{ld} - TO_{tr}).

3. RESULTS

Comparison of standing posture under basal (stim off), unilateral and bilateral stimulation conditions evidenced significant differences both in the static posture before movement initiation and during the gait initiation process. Concerning the static phase (see fig. 2), STN stimulation induced a reduction of the forward trunk bending and shank inclination, with a consequent reduction of the moment at the hip and ankle joints and a backward shift of the COP.

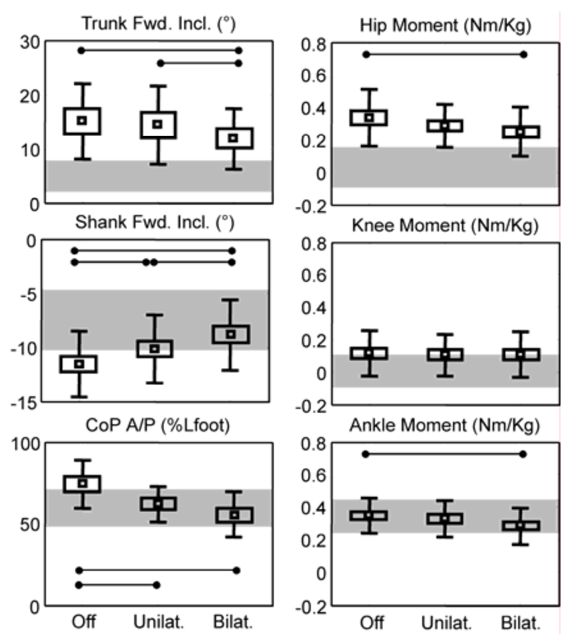

Fig. 2 – Box plots of the main parameters related to the standing posture of PD subjects in basal condition, unilateral and bilateral STN stimulation. +/- 1 SD band of controls is superimposed.

To assess if attentionally demanding condition associated with preparation to walk in response to an external cue might influence the efficacy of STN stimulation, a comparison was performed with the trials where patients were asked to maintain a quite standing posture. Results indicated that the effects of STN stimulation were more consistent in the standing preceding the gait initiation cue gait than during quite standing.

In fig.3 two examples of the COP trajectory during gait initiation of a PD patient under basal and bilateral STN stimulation condition is shown.

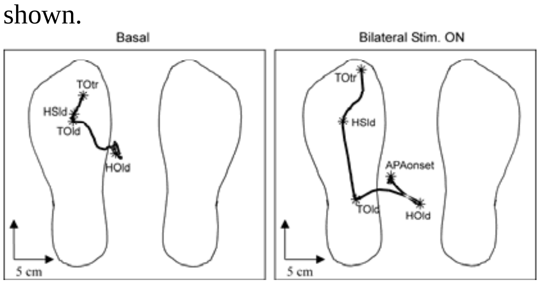

Fig. 3 – COP trajectory of a PD patient in basal (left) and bilateral STN stimulation condition (right).

A recovery of the physiological imbalance and unloading phase can be observed under the stim-on condition, characterised by larger backward and lateral COP displacement. Moreover, the duration of these subphases significantly reduced toward the control values (see fig. 4). Finally, an increase in the first step length / height and in gait velocity was found.

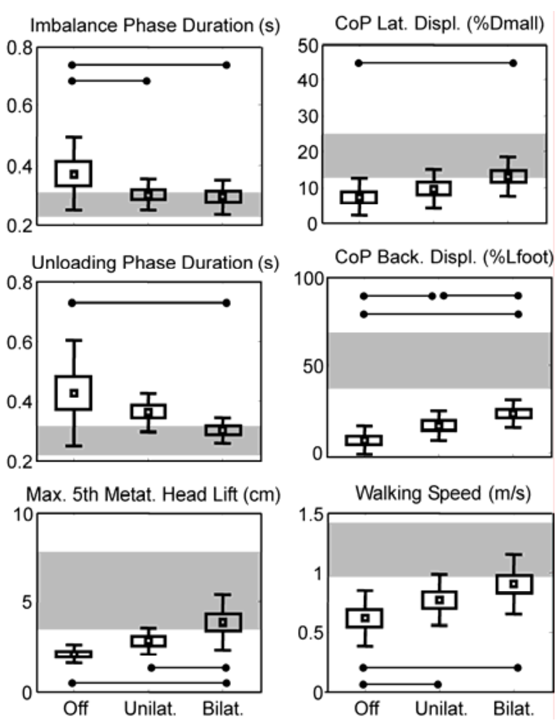

Fig. 4 – Box plots of the main parameters related to the gait initiation process of PD subjects in basal condition, unilateral and bilateral STN stimulation. +/- 1 SD band of controls is superimposed.

All the above changes were more consistent in bilateral than in unilateral STN stimulation.

4. DISCUSSION AND CONCLUSIONS

Our results demonstrate that stimulation of STN in PD patients influence the gait initiation process in the following aspects: improvement of the initial standing posture (especially in attentional-demanding conditions), with a reduction of the exaggerated trunk, thigh and shank inclination; restoration of the anticipatory postural action responsible for the forward body fall associated with the first step; improvement in the execution of the first step, in terms of increase of length and velocity and of lift of the forefoot. Therefore, STN stimulation seems to influence two motor programmes, one associated with the anticipatory postural adjustments and the second to locomotion; moreover STN stimulation might effectively act on the appropriate sequencing of motor programmes, which possibly underlies the disturbed gait onset in PD patients [4].

These findings confirm the interaction of STN-stim with functionally basic motor control systems, but suggest a substantial impact on structures related to cognitive data processing and motor memory.

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Acknowledgements

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