Characterization of Postural Steadiness of Post-Stroke Hemiplegic Patients by Force Platform Data Analysis

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Abstract

Hemiplegia, resulting after cerebrovascular accident or stroke, is a condition in which one-half of a patient's body is paralyzed. In most of the cases post-stroke survivors show improper and poor postural steadiness. Postural steadiness or stance stability characterizes the dynamics of the postural control system and postural sway associated with maintaining balance during quiet standing. Researchers have also reported that post stroke hemiplegic patients bear motor, sensory, balance, speech and perceptuo-cognitive deficits. Such patients also show increased body sway, asymmetric weight bearing capacity and a greater center of pressure (COP) excursion at the affected side during quiet standing compared to people without central nervous system disorders. In this paper an attempt is made to characterize the postural steadiness of hemiplegic patients using a force platform, also known as stabilometer. A force platform-an effective and reliable tool for quantifying the postural steadiness of patients with postural dyscontrol - measures the displacement of the COP, the horizontal and vertical ground reaction forces.

This research paper aims to quantify and assess the postural steadiness of 25 post stroke hemiplegic patients (age 30-70 yrs) compared to age-matched normal control group (30 normal subjects, age 30-70 yrs) using COP-based parameters obtained from force platform data and identify the statistically significant variables using ANOVA test. Similar studies have rarely been performed in Indian health care system concerning the rehabilitation of post stroke hemiplegic patients. The results of this study would help researchers and medical professionals to evaluate statistically significant COP-based parameters and clinically correlate them with static balance of hemiplegic patients.

Keywords- Postural steadiness, Hemiplegic posture, Stabilometry, Force platform, Static posturography, Stance Stability post-stroke.

Introduction

In recent trend of health care system, stroke or cerebrovascular accident is fast emerging as a major public health problem in India and other developing countries. Stroke is a sudden loss of brain function resulting from an interference with blood supply to the brain. Stroke is one of the major causes of human morbidity and mortality. Population-based estimates confirm a rising trend in both incidence and prevalence of stroke in India (Kaul *et al*., 2007). For post stroke patients, motor deficits are characterized by paralysis (hemiplegia) or weakness (hemiparesis), typically on the side of the body opposite the side of the lesion. Hemiplegia is a condition in which one-half of a patient's body is paralyzed. Hemiplegic patients exhibit motor, sensory, balance, speech and perceptuo-cognitive deficits. Post stroke hemiplegic patients show an increased body sway (Bonan *et al*., 2004), asymmetric weight bearing capacity (Bohannon *et al*., 1985; Dickstein *et al*., 1984) and greater center of pressure (COP) excursion at the affected side (Pai *et al*., 1994) during quiet standing compared to people without central nervous system disorders. Post stroke hemiplegics have decreased trunk control, poor bilateral integration and impaired automatic postural control resulting in balance dysfunction (Shah *et al*., 2006). Postural instability (PI) is common in patients following stroke, especially as the disease severity advances (Sackley *et al*., 1993).

The aim of stroke rehabilitation is to reduce the disabilities and enable the patient to return to community. Needless to say, it is very essential to undergo and assess the postural steadiness of post stroke hemiplegic patients in rehabilitation point of view. Postural steadiness is the dynamics of the postural control system associated with maintaining balance during quiet standing. Postural steadiness is most often characterized with measures based on the displacement of the center-of-pressure (COP) measured with a force platform. The COP reflects the orientations of the body segments, as well as the movements of the body to keep the center-of-gravity over the base-of-support. The planar trajectory of the COP over the test interval is commonly referred to as a stabilogram. Postural steadiness evaluations often include both eyes-open and eyes-closed trials to estimate the role of the visual system in maintaining standing balance. Postural dyscontrol in the stroke patients may reflect subclinical pathologies affecting one or more components of the postural control system, as well as changes in the sensorimotor systems. Characterizing such changes in postural steadiness will advance our understanding of the ways in which the postural control system is compromised with the aging process, and may provide information useful in identifying post stroke patients at risk of falling.

Materials and Methods

Subjects

A patient group of 25 post stroke hemiplegic patients of age 30-70 yrs (50.64±11.96 yrs) with BMI (23.46±3.19) Kg/m^2 and the control group of 30 normal healthy persons of age 30-70 yrs (46.3±12.28 yrs) with BMI (22.58±2.98) Kg/m^2 participated in this study. Recruited subjects were informed of the purpose of the study and each of them gave their written consent. The hemiplegic patient group met the following inclusion criteria: (a) subjects with least 1-months post stroke period, (b) subjects able to stand at least 75 sec. on a plane rigid planer base parallel to the horizontal floor of a room without any aid, (c) subjects with drop-foot, (d) subjects under medication and having stable medical conditions; exclusion criteria were: (a) individuals with receptive aphasia, cognitive or perceptual deficits, (b) individuals with history of a previous stroke, (c) history of any other musculoskeletal or orthopaedic diseases, (d) absence of muscle tone abnormalities and motor or sensory deficits in the non-paretic limbs, (e) individuals with inner ear diseases. The control group had no neurological or orthopaedic deficits involving the arms, legs, or trunk.

Methods

The study was performed by using a two-load cell based force platform (stabilometer) that was connected to a computer through LABJACK data Acquisition System. This force platform—developed by School of Bioscience & Engineering, Jadavpur University (Kolkata, India) — belongs to the Gait Laboratory of National Institute for the Orthopaedically Handicapped (NIOH), Bonhoogly (Kolkata, India). A Force platform (Fig. 1A) is constructed by two plates, separated by two octagonal rings (Load cell). This platform is a mechanically stiff and stationary system so that the natural frequency (a resonant frequency of 1 KHz is common) of platform is well above the frequencies of the ground reaction force being measured.

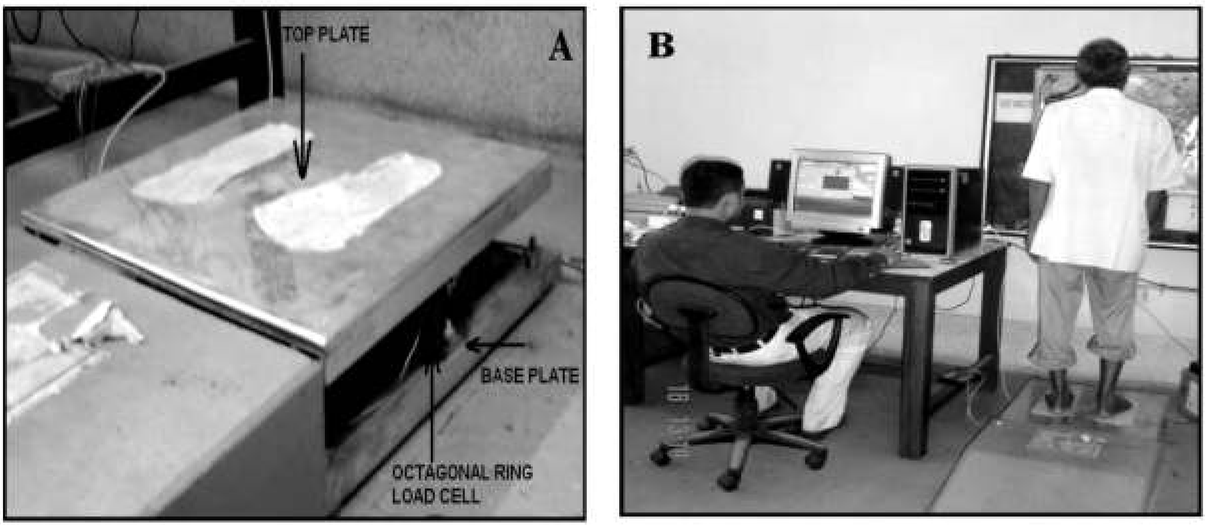

Figure 1: (A) Two load cell based force platform (B) Data recording set-up.

The electronic signal conditioning circuit of the stabiolmeter (force platform) includes strain gauge, strain gauge excitation voltage supply, strain gauge amplifier and power supply unit. The amplifier output goes to LABJACK-DAS followed by a computer with necessary software for collecting, storing and analyzing the data in the computer. Data collection was started when the subject was in perfect condition according to the requirement. The duration of data collection was set to 75 seconds. For this study, each subject (patient or normal) had to undergo stabilometry test both in eye-open and eye-closed conditions. For the eyes-open trial, each subject was asked to stand quietly in a comfortable stance near the center of the force platform, with arms at the side, and look straight ahead at a visual reference (Fig. 1B). Data recording and storing operation were performed by Lab Jack software in graphical form. After the eyes-open trial, the subject was asked to sit in a chair for approximately two minutes before the procedure was repeated with eyes closed. The output of the force platform filtered by low pass filter connected to data acquisition LAB JACK card. Data sampling frequency was 50Hz. The raw data was processed and analyzed using MS-Excel software.

Evaluation of Cop Based Time Domain Parameters

The COP path is defined by anterior-posterior (AP) and medial-lateral (ML) time series relative to the origin of the force platform coordinate system. The positions of the mean COP on the force platform are defined by the arithmetic means of the AP and ML time series. The mean of AP and ML can be defined by following equation (Prieto *et al.* 1996).

$$AP = 1/N \sum_{1}^{N} AP[n] \quad \ldots(1)$$

$$ML = 1/N \sum_{1}^{N} ML[n] \quad \ldots(2)$$

where, n=1, 2… N and AP[n] and ML[n] are time series data on COP path. To simplify the following definitions, the AP and ML time series are referenced to the mean COP.

$$Y[n] = AP[n] - \overline{AP} \quad \ldots(3)$$

$$X[n] = ML[n] - \overline{ML} \quad \ldots(4)$$

where, Y= deviation of AP time series data and X= deviation of ML time series data.

AP-Range and ML-Range

The range is the maximum distance between any two points on the COP path. The AP-range is the absolute value of the difference between the smallest and largest values in AP time series. Similarly the ML-range is the absolute value of the difference between the smallest and largest values in ML time series.

Resultant Distance (RD)

It is the vector distance from the mean COP to each pair of points in the AP and ML time series.

$$RD=(X[n]^2 + Y[n]^2)^{1/2} \quad ...(5)$$

Mean Distance (MDIST)

It is the mean of the RD and represents the average distance from the mean COP.

$$MDIST = 1/N \sum RD[n] \quad ...(6)$$

Mean Distance-AP ($MDIST_{AP}$)

It is the mean absolute value of the AP time series and represents the average AP distance from the mean COP.

$$MDIST_{AP} = 1/N \sum |Y[n]| \quad ...(7)$$

Mean Distance-ML (MD_{ML})

It is the mean absolute value of the ML time series and represents the average ML distance from the mean COP.

$$MDIST_{AP} = 1/N \sum |X[n]| \quad ...(8)$$

RMS Distance (RDIST)

RDIST from mean COP is the RMS value of the RD.

$$RDIST = [1/N \sum RD[n]^2]^{1/2} \quad ...(9)$$

RMS Distance-AP ($RDIST_{AP}$)

RDISTAP from mean COP is the standard deviation of the AP time series

$$RDIST_{AP} = [1/N \sum Y[n]^2]^{1/2} \quad \ldots(10)$$

RMS Distance-ML ($RDIST_{ML}$)

$RDIST_{ML}$ from the mean COP is the standard deviation of the ML time series

$$RDIST_{ML} = [1/N \sum X[n]2]^{1/2} \quad ...(11)$$

Total Excursions (TOTEX)

It is the total length of the COP path, and is approximated by the sum of the distances between consecutive points on the COP path.

$$\text{TOTEX} = \sum_{1}^{N-1} [(X[n+1]-X[n])^2 + (Y[n+1]-Y[n])^2]^{1/2} \qquad \ldots (12)$$

Total Excursions ($TOTEX_{AP}$)

It is the total length of the COP path in the AP direction, and is approximated by the sum of the distances between consecutive points in the AP time series.

$$\text{TOTEX AP} = \sum_{n-1}^{N-1} \left| Y[n+1]-Y[n] \right| \qquad \ldots (13)$$

Total Excursions ($TOTEX_{ML}$)

It is the total length of the COP path in the ML direction, and is approximated by the sum of the distances between consecutive points in the ML time series.

$$\text{TOTEX ML} = \sum_{n-1}^{N-1} \left| X[n+1]-X[n] \right| \qquad \ldots (14)$$

Mean Velocity (MVEL)

It is the average velocity of the COP, can be written as total distance covered divided by the time period (T). Here time period is 75 sec.

$$\text{MVEL} = \text{TOTEX}/T \qquad \ldots (15)$$

Mean Velocity-AP ($MVEL_{AP}$)

It is the average velocity of the COP in the AP direction, can be written as total distance covered in AP direction divided by the time period (T),

$$MVEL_{AP} = TOTEX_{AP}/T \qquad \ldots (16)$$

Mean Velocity-ML ($MVEL_{ML}$)

It is the average velocity of the COP in the ML direction, can be written as total distance covered in ML direction divided by the time period (T),

$$MVEL_{ML} = TOTEX_{ML}/T \qquad \ldots (17)$$

Sway Area (AREA-SW)

The area enclosed by the COP path per unit of time and can be conceptualized as proportional to the product of mean distance and mean velocity, represented as,-

$$\text{AREA-SW} = 1/2T \sum_{1}^{N-1} |Y[n+1]X[n]-Y[n]X[n-1]| \qquad \ldots (18)$$

95% Confidence Ellipse Area (AREA-CE)

The approach of the confidence ellipse is based on the assumption that the distribution of the points is a Normal bivariate distribution (Prieto *et al.*, 1996), which is expected to enclose approximately 95% of the points on the COP path.

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$$AREA\text{-}CE = 2\pi F_{.05[2,n-2]}[S^2_{AP} S^2_{ML} - S^2_{APML}]^{1/2} \quad \ldots(19)$$

where, $F_{.05[2,n-2]}$ is the F statistic at a 95% confidence level for a bivariate distribution with n data points. For large sample size (n>120), $F_{.05[2,\infty]}$ is 3.00 (Prieto *et al.*, 1996). SAP and SML are the standard deviations of the AP and ML time series, respectively. SAP ML is the covariance and can be written as –

$$SAP\,ML = \sum_{1}^{N} 1/N\ Y[n]\,X[n] \quad \ldots(20)$$

95% Confidence Circle Area (AREA-CC)

This models the area of the stabilogram with a circle that includes approximately 95% of the distances from the mean COP, assuming that the distances are normally distributed.

$$AREA\text{-}CC = \pi(MDIST + Z_{0.05}S_{RD})^2 \quad \ldots(21)$$

where $Z_{0.05}$, the z statistic at the 95% confidence level, is 1.645 (Prieto *et al.*, 1996), and S_{RD} is the standard deviation of the RD time series.

$$S_{RD} = [RDIST^2 - MDIST^2]^{1/2} \quad \ldots(22)$$

Results

The COP based parameters obtained in this study (both in eye-open and eye-closed trials) using force platform data both for normal healthy control group and hemiplegic patient group and statistically significant parameters (after ANOVA test) are listed in Table 1.

Table 1: COP Based Parameters of Patient Group and Control Group.

Parameters	**Control Group**		**Hemiplegic Patient Group**		**p-Values**	
	EO	**EC**	**EO**	**EC**	**EO**	**EC**
Mean Distance (mm)	–	3.69±0.44	3.48±0.48	4.06±0.93	NS	<0.05
Mean Distance-AP (mm)	2.27±0.29	2.66±0.52	2.45±0.52	3.08±0.98	NS	<0.05
Mean Distance-ML (mm)	2.05±0.21	2.08±0.20	2.02±0.22	2.12±0.22	NS	NS
RMS Distance (mm)	3.64±0.35	4.08±0.57	3.83±0.63	4.61±1.20	NS	<0.04
RMS Distance-AP (mm)	2.79±0.41	3.30±0.67	3.02±0.68	3.86±1.27	NS	<0.05

RMS Distance-ML (mm)	2.32±0.22	2.38±0.22	2.33±0.26	2.48±0.29	NS	NS
Range (mm)	19.5±7.55	22.7±8.13	23.9±8.57	27.8±7.33	<0.05	<0.02
Range-AP (mm)	15.7±3.31	19.3±4.89	18.3±7.9	23±7.23	NS	<0.03
Range-ML (mm)	9.55±1.2	10.4±1.38	11.7±6.77	11.6±2.39	NS	<0.03
Mean Velocity (mm/s)	25.3±10.2	25.9±10.1	24.0±9.10	26.1±8.97	NS	NS
Mean Velocity -AP (mm/s)	15.6±5.99	16.2±5.87	15.4±5.32	17.5±5.83	NS	NS
Mean Velocity -ML (mm/s)	17.1±7.36	17.3±7.39	15.7±6.68	16.3±6.30	NS	NS
95% Conf. Ellipse Area (mm^2)	110.8±20.3	131.9±33.6	116.9±30.8	151.2±52.5	NS	NS
95% Conf. Circle Area (mm^2)	102±26.9	138.7±49.3	121.4±53	190.6±130	NS	<0.03
Sway Area (mm^2/s)	31.5±14.7	34.0±14.9	29.0±12.9	34.5±14.9	NS	NS

(Note: NS=Not Significant (p>0.05), EO=Eye-Open, EC=Eye-Closed)

Figure 2 (A, B and C) represent the comparative views of stabiograms (COP excursion path), AP variations and ML variations respectively, between a hemiplegic patient and a normal control in this study both for eye-open (EO) and eye-closed (EC). These figures emphasis that the patient showed larger COP excursion path, AP-variation and ML-variation compared to the normal control both for eye-open and eye-closed trials respectively.

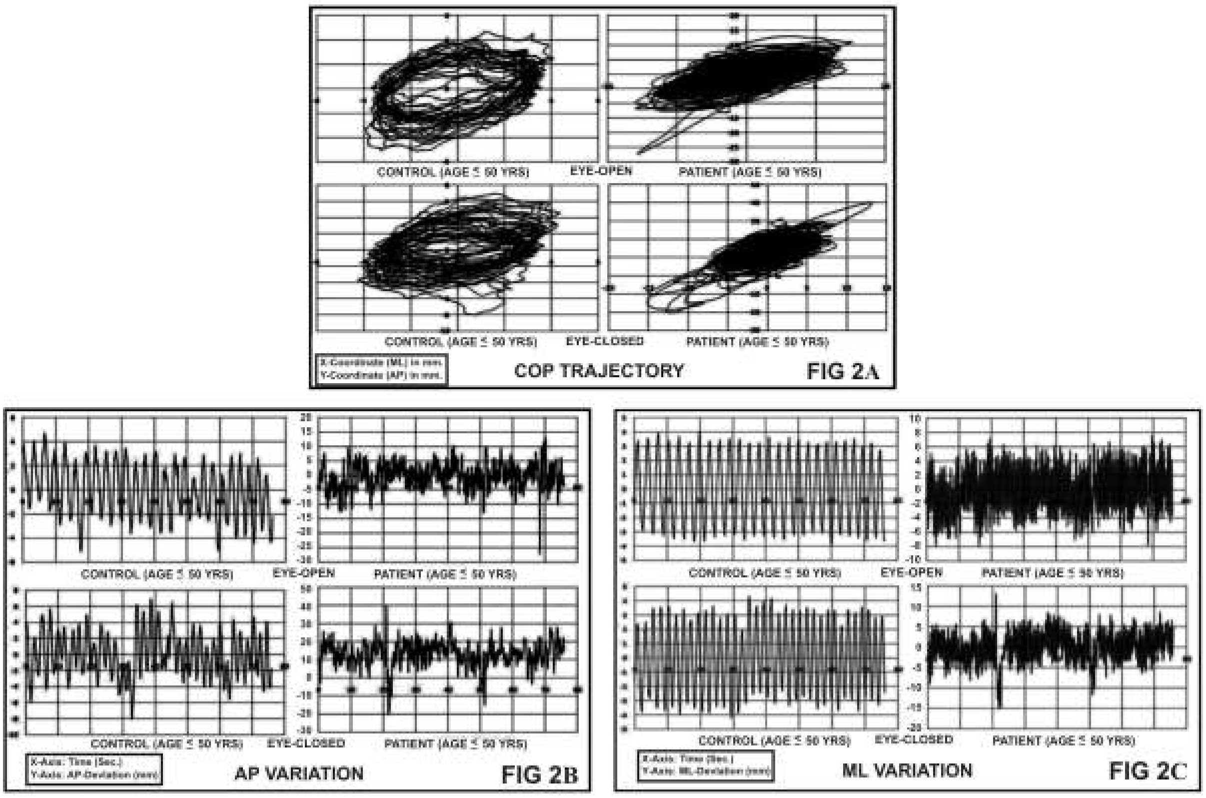

Figure 2: (A) Stabilograms (B) AP-variations (C) ML-variations between a control and a patient both for eye-open and eye-closed conditions.

Figure 3 & Figure 4 (A, B, C) furnish and quantify the comparative aspects corresponding to the statistically significant COP based parameters obtained after analyzing force platform data in eye-open and eye-closed conditions respectively.

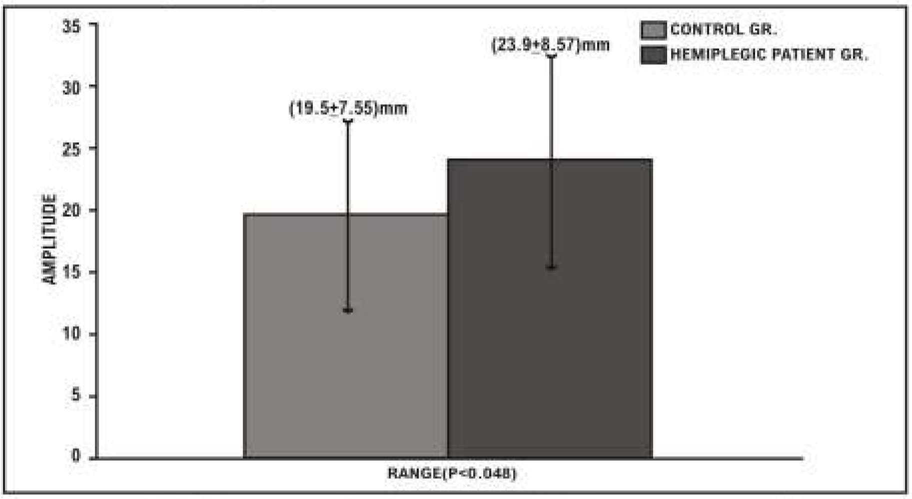

Figure 3: Significant COP-based parameter in the eye-open condition.

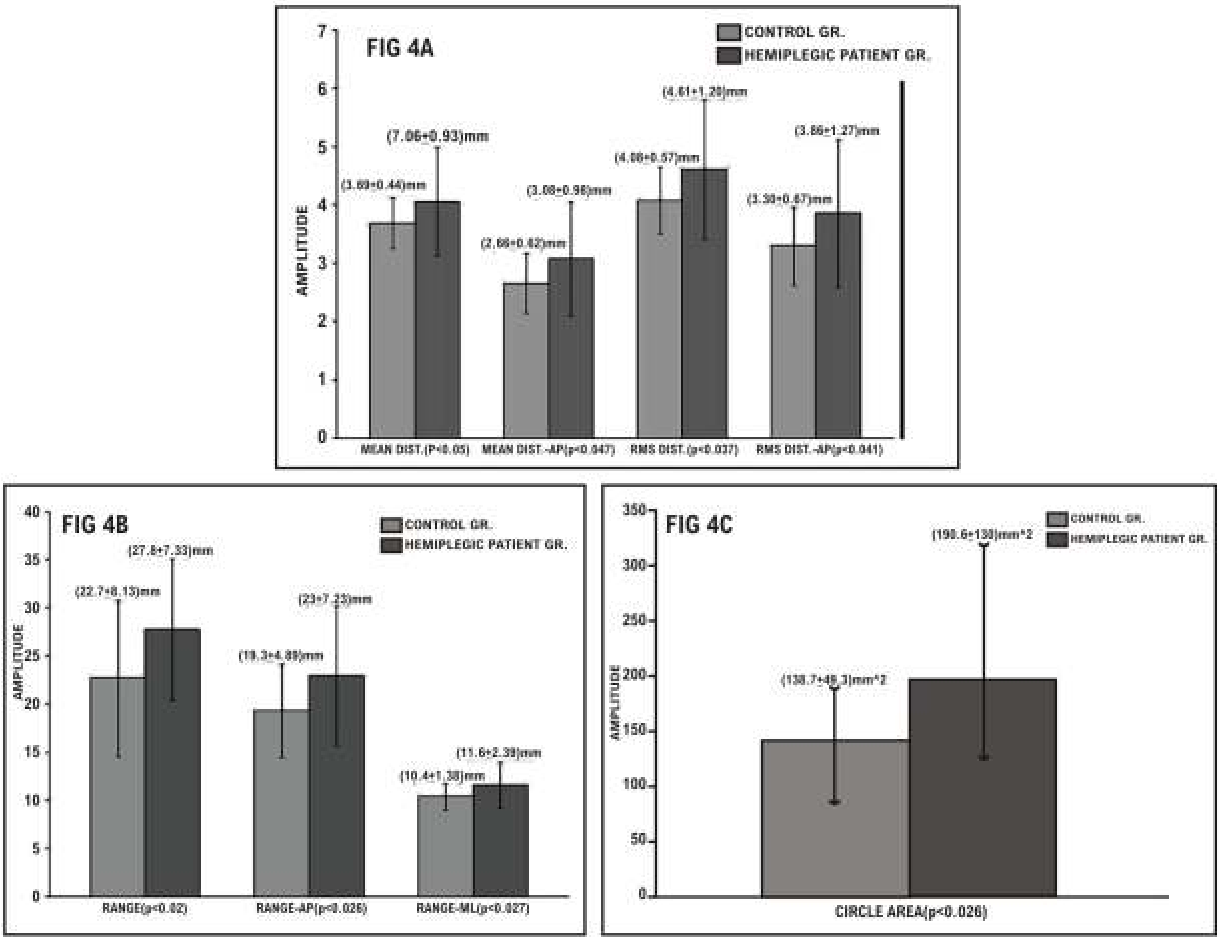

Figure 4(A, B, C): Significant COP-based parameters in the eye-closed condition.

The ANOVA test for this study involving hemiplegic patient group (age 30-70 yrs) and age-matched normal healthy control group showed the following results: For eye-open condition, the parameter, range ($p<0.05$) was significantly larger (Fig. 4) for the patient group than the control group. For eye-closed condition, following parameters were significantly larger for patient group compared to the control group: Mean distance ($p<0.05$), Mean distance-AP ($p<0.05$), RMS distance ($p<0.04$), RMS distance-AP ($p<0.05$) (Fig. 4A), Range ($p<0.02$), Range-AP ($p<0.03$), Range-ML ($p<0.03$) (Fig. 4B), and Circle area ($p<0.03$) (Fig. 4C).

Discussion

It is known that a human use three basic mechanisms to obtain a sense of balance in daily life. The three mechanisms (visual, vestibular, and proprioceptive) interact to maintain posture and impart a conscious sense of orientation and interact and commonly control postural sway in quiet standing (Horváth *et al*., 2005). Loss of one of these factors or its perturbation increases body sway, namely, the movement of the center of gravity or center of pressure. Visual inputs aid in the maintenance of an upright posture and in orientation. Conscious and unconscious correction of posture is possible through processing visual inputs. This study, based on the presence (eye-open) and absence (eye-closed) of a visual reference, reveals that hemiplegic patient group (age 30-70 yrs) exhibited a significant difference in range while compared to the age matched healthy normal control group both in eye-open and eye-closed trials. The other 14 parameters (in eye-open trial), although showed no statistical significance are larger for hemiplegic patient group compared to control group. For eye-closed condition, hemiplegic patients showed significant differences in (a) Mean distance, Mean distance-AP (Horváth *et al*., 2005; Ustinova *et al*., 2004), (b) RMS distance, RMS distance-AP (Corriveau *et al*., 2004; Niam *et al*., 1999) (c) Range, Range-AP, Range-ML (Priplata *et al*., 2006), and Circle area while compared to control group.

Conclusion

It can be concluded from the above study that the overall stance stability of hemiplegic patient group of age 30-70 years is poorer than the age matched control group and such postural instability is much evident (statistically significant) in absence of any visual reference. Hence, post-stroke hemiplegic patients bear standing balance deficits compared to age matched control group. However, similar studies, (despite the support of previous studies) have rarely been performed in India. Thus, focusing more attention in the field of stabilometry of hemiplegic patients may help researchers and medical professionals to evaluate and clinically correlate the statistically significant COP-based parameters with static balance of hemiplegic patients.

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