STANCE STABILITY ANALYSIS OF BELOW FIFTY YEARS AGE POST-STROKE HEMIPLEGIC PATIENTS BY STABILOMETRIC METHOD

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Abstract: In hemiplegia, caused by cerebrovascular accident or stroke, one-half of a patient's body is paralyzed. Post-stroke hemiplegic survivors have an increased risk of falling and hip fractures, leading to decreased physical activity, social deprivation and eventually, loss of independence. Balance deficits after stroke comprise reduced postural stability during quiet standing and delayed and less coordinated responses to both self-induced and external balance perturbations. Gait deficits include reduced propulsion at push-off, decreased hip and knee flexion during the swing phase, and reduced stability during the stance phase. This paper sheds lights on a comparative study on the stance stability between post-stroke hemiplegic patients group (age 28-50 yrs) and age-matched normal control group, using a force plate, also termed as stabilometer. Similar studies have rarely been performed in Indian health care system concerning the rehabilitation of post stroke hemiplegic patients. This research paper aims to quantify and assess the postural steadiness of 12 post stroke hemiplegic patients compared to age-matched normal control group (18 normal subjects) using standard COP (Centre of pressure) based parameters and identify the statistically significant variables using ANOVA test. The results of this study will 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 plate, hemiplegia.

1. INTRODUCTION

Stroke is a sudden loss of brain function resulting from an interference with blood supply to the brain. It limits stroke to an acute vascular phenomenon that includes ischemic strokes and hemorrhagic strokes. Stroke is one of the major causes of human morbidity and mortality in adults [1]. Although approximately two thirds of the affected patients are above 65 years, a stroke may occur at all ages, even in very young children, and can have many causes [2, 3]. Stroke is one of the major causes of permanent disability with an incidence of approximately 1.75% per year [2].

A majority of the stroke survivors have a combination of sensory, motor, cognitive [2, 4, 5] and emotional impairments leading to restrictions in their capacity to perform basic activities of daily living (ADL) [1, 2, 6]. Of all possible sensorimotor consequences of stroke, impaired postural control probably has the greatest impact on ADL independence and gait [2, 4, 7–10]. Stroke-related impairments commonly are associated with weight bearing asymmetry [11-13], poor static and dynamic balance [1, 4, 11, 14, 15], and disturbances in postural alignment [11, 16], increasing the incidence of falls [1]. Research based studies on stroke patients have identified reduced loading on the paretic lower limb [4,17-22] and increased postural sway during quiet standing [4, 17, 19, 21-23] as well as delayed and disrupted equilibrium reactions and impaired anticipatory postural adjustments to body perturbations, especially in the affected leg [4, 24-27]. Together with a general slowness of information processing, this combination of postural deficits causes slow and inflexible motor behavior during various activities of daily life [4, 28-30].

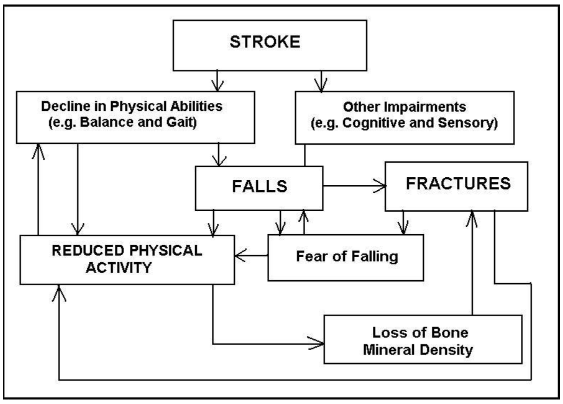


Fig. 1: The interactions between risk factors, fall and consequences of falls in persons with stroke

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. Population-based estimates confirm a rising trend in both incidence and prevalence of stroke in India [31]. 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 postural sway [4, 5, 17, 19, 21-23, 32], asymmetric weight bearing capacity [5, 12, 33, 34], and greater center of pressure (COP) excursion at the affected side [5, 35] during quiet standing compared to people without central nervous system disorders. Post stroke hemiplegic patients have decreased trunk control, poor bilateral integration and impaired automatic postural control resulting in balance dysfunction [5, 36]. Postural instability (PI) is common in patients following stroke, especially as the disease severity advances [5, 37]. Fig. 1 furnishes the interactions between risk factors, fall and consequences of falls in persons with stroke.

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 [5]. Force platforms appear to be the balance assessment instrumentation most suited to the clinical situation since they produce a real-time display and can detect small changes in subjects' ability to maintain their balance. They are therefore suitable for thorough evaluations of balance and for monitoring patients' progress [38]. 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.

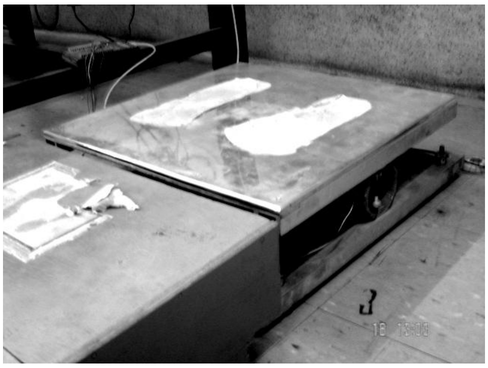
2. MATERIALS AND METHODS

2.1. Subjects

A patient group of 12 post stroke hemiplegic patients of age 28-50 yrs (41.5±8.59 yrs) with BMI (24.44±3.48) kg/m^2 and the control group of 18 normal healthy persons of age 28-50 yrs (38±6.69 yrs) with BMI (22.17±2.97) kg/m^2 were recruited in this study. All of recruited subjects were informed of the purpose of the study and subjects voluntarily participated and each of them signed a consent form. The hemiplegic patient group met the following inclusion criteria: (a) subjects with least 1-month 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.

2.2. Methods

The study was performed by using a two-load cell based force plate (stabilometer) that was connected to a computer through LABJACK data Acquisition System (DAS). This stabilometer, developed by School of Bioscience and Engineering, Jadavpur University (Kolkata, India) belongs to the Gait Laboratory of National Institute for the Orthopaedically Handicapped (NIOH), Bonhoogly (Kolkata, India). A Force plate (Fig. 2A) 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.



(A)

(B)

Fig. 2: (A) Two load cell based force plate (B) LABJACK—DAS

The electronic signal conditioning circuit of the stabilometer includes strain gauge, strain gauge excitation voltage supply, strain gauge amplifier and power supply unit. The amplifier output goes to LABJACK-DAS (Fig. 2B) followed by a computer with necessary software for collecting data and analyzing those data in PC. 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. 3A). Data recording operation was performed by Lab Jack software that recorded data in graphical form (Fig. 3B).

(A)

(B)

Fig. 3: (A) Data recording set-up (B) Data recording by Lab Jack software

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 plate filtered by low pass filter (cut off frequency 10Hz), connected to data acquisition LAB JACK card. Data sampling frequency was 50Hz. The raw data was processed and analyzed using MS-Excel software.

2.3. 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 plate coordinate system. The positions of the mean COP on the force plate 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 [39].

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

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

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.

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

Y= deviation of AP time series data.

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

X= deviation of ML time series data.

a) 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.

b) Resultant Distance (RD): It is the vector distance from the mean COP to each pair of points in the AP and ML time series.

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

c) Mean Distance (MDIST): It is the mean of the RD and represents the average distance from the mean COP.

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

d) 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.

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

e) 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.

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

f) RMS Distance (RDIST): RDIST from mean COP is the RMS value of the RD.

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

g) RMS Distance-AP ($RDIST_{AP}$): $RDIST_{AP}$ from mean COP is the standard deviation of the AP time series

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

h) RMS Distance-ML ($RDIST_{ML}$): $RDIST_{ML}$ from the mean COP is the standard deviation of the ML time series

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

i) 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.

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

j) 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.

$$TOTEX_{AP} = \sum_{n=1}^{N-1} |Y[n+1] - Y[n]| \quad (13)$$

k) 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.

$$TOTEX_{ML} = \sum_{n=1}^{N-1} |X[n+1] - X[n]| \quad (14)$$

l) 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.

$$MVEL = TOTEX/T \quad (15)$$

m) 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),

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

n) 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),

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

o) 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-

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

p) 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 [39], which is expected to enclose approximately 95% of the points on the COP path.

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

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 [39]. S_{AP} and S_{ML} are the standard deviations of the AP and ML time series, respectively. $S_{AP\ ML}$ is the covariance and can be written as –

$$S_{AP\ ML} = 1/N \sum_{1}^{N} Y[n]\,X[n] \qquad (20)$$

q) 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.

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

where $Z_{0.05}$, the z statistic at the 95% confidence level, is 1.645 [39], and S_{RD} is the standard deviation of the RD time series.

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

3. RESULTS AND DISCUSSIONS

3.1. Results

The COP based parameters obtained in this study (both in eye-open and eye-closed trials) using force plate 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		Patient Group		p-Values	
	EO	EC	EO	EC	EO	EC
Mean Distance (mm)	3.32±0.24	3.63±0.45	3.45±0.43	4.16±0.82	NS	<0.04
Mean Distance-AP (mm)	2.24±0.28	2.60±0.60	2.44±0.50	3.20±0.89	NS	<0.04
Mean Distance-ML(mm)	2.03±0.15	2.06±0.14	2.04±0.24	2.16±0.20	NS	NS
RMS Distance (mm)	3.59±0.33	3.99±0.60	3.82±0.56	4.75±1.06	NS	<0.02
RMS Distance-AP (mm)	2.74±0.41	3.18±0.74	3.02±0.65	4.04±1.13	NS	<0.03
RMS Distance-ML (mm)	2.31±0.17	2.35±0.15	2.32±0.28	2.48±0.27	NS	NS
Range (mm)	18.7±4.85	21.1±5.88	24.8±10.7	28.3±8.06	<0.05	<0.01
Range-AP (mm)	15.5±3.41	18.1±4.63	20.1±10.3	24.7±5.65	NS	<0.003
Range-Ml (mm)	9.42±0.92	10.1±1.12	13.3±9.87	14.5±2.07	NS	<0.007
Mean Velocity (mm/s)	24.7±11.3	25.1±11.2	27.2±10.8	29.9±9.22	NS	NS
Mean Velocity-AP (mm/s)	16.6±8.09	16.7±8.16	17.4±6.11	19.9±5.59	NS	NS
Mean Velocity-ML (mm/s)	15.3±6.72	15.8±6.54	17.8±8.11	18.8±6.78	NS	NS
95% Conf. Ellipse Area (mm^2)	107±16.5	124±24.8	115±24.0	152±36.7	NS	<0.03
95% Conf. Circle Area (mm^2)	98.9±26.4	130±51.1	122±46.6	208±111	NS	<0.02

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

Fig. 4 and Fig. 5 represent the comparative views of AP variations between a hemiplegic patient and a control in this study both for eye-open (EO) and eye-closed (EC) conditions respectively, whereas ML variations are depicted in Fig. 6 and Fig. 7 respectively.

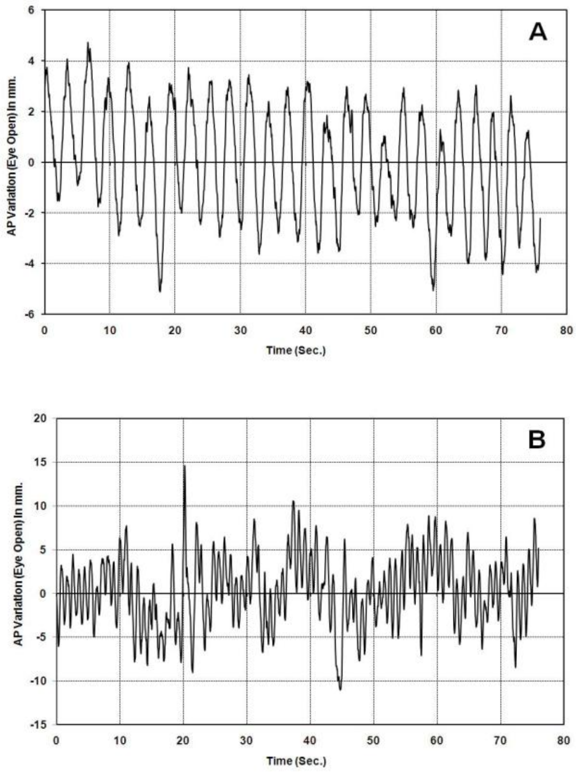


Fig. 4: AP variation (EO); (A) control (age ≤ 50 yrs) (B) patient (age ≤ 50 yrs)

Fig. 8 and Fig. 9 (A, B, C) furnish and quantify the comparative aspects corresponding to the evaluated COP based parameters obtained after statistically analyzing force plate data in eye-open and eye-closed conditions respectively.

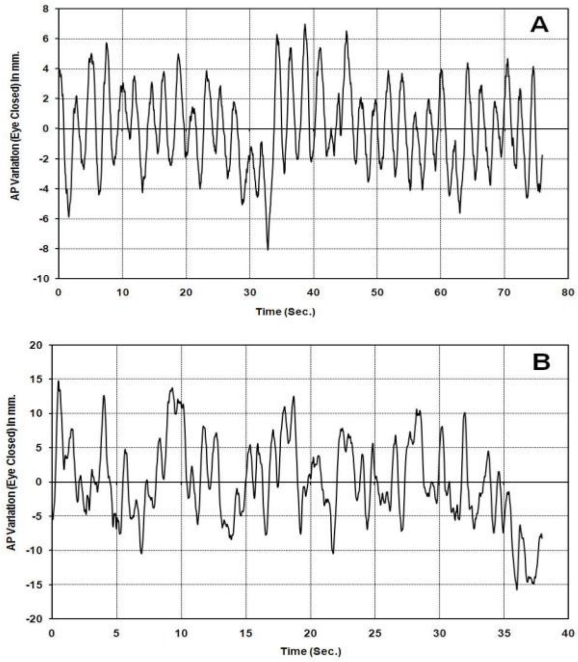


Fig. 5: AP variation (EC); (A) control (age ≤ 50 yrs) (B) patient (age ≤ 50 yrs)

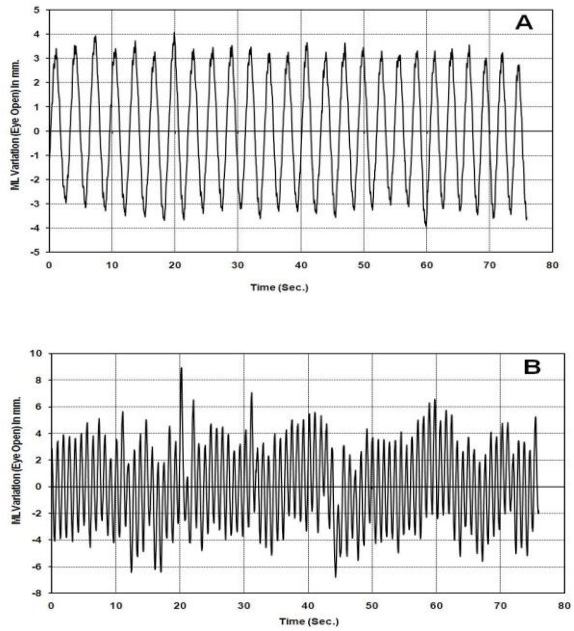


Fig. 6: Ml variation (EO); (A) control (age ≤ 50 yrs) (B) patient (age ≤ 50 yrs)

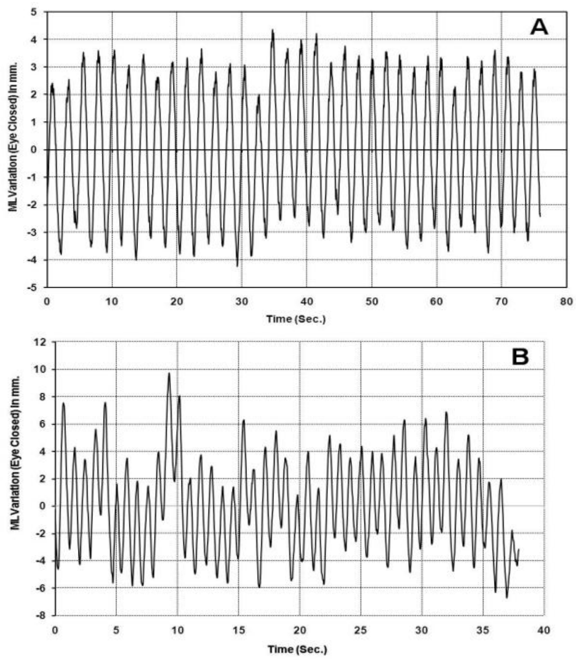


Fig. 7: ML variation (EC); (A) control (age ≤ 50 yrs) (B) patient (age ≤ 50 yrs)

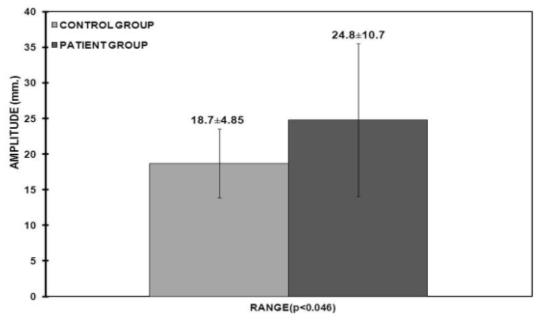


Fig. 8: Significant COP-based parameter in the eye-open condition

It is clear from the above study involving normal healthy control group (age ≤ 50 yrs) and hemiplegic patient group (age≤50 yrs) that the ANOVA test showed the following results: For eye-open condition, the parameter, range ($p<0.05$) was significantly larger for the patient group than the normal controls. For eye-closed condition, following parameters were significantly larger for patient group compared to the control group: mean distance ($p<0.04$), mean distance-AP ($p<0.04$), RMS distance ($p<0.02$), RMS distance-AP ($p<0.03$), range ($p<0.01$), range-AP ($p<0.003$), range-ML ($p<0.007$), 95% confidence ellipse area ($p<0.03$), 95% confidence circle area ($p<0.02$).

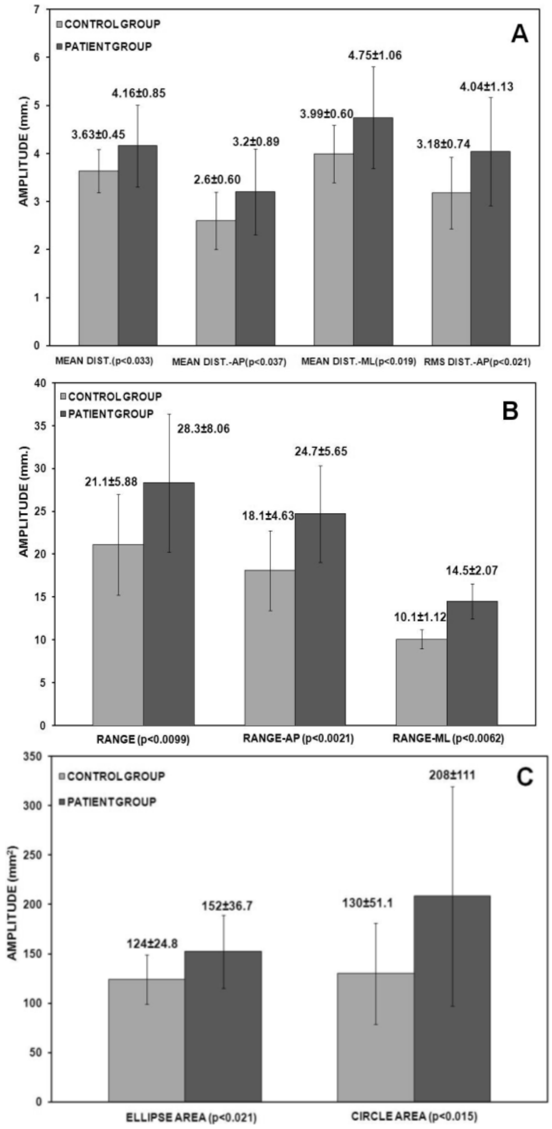


Fig. 9(A, B, C): Significant COP-based parameters in the eye-closed condition

3.2. 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 [40]. 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, although based on the presence (eye-open) and absence (eye-closed) of a visual reference, reveals that hemiplegic patient group of below 50 years age 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 mean distance, mean distance-AP, RMS distance, RMS distance-AP, range, range-AP, range-ml, 95% confidence ellipse area and 95% confidence circle area while compared to control group. The use and significance of mean distance-AP as COP based parameter has also been proved by Ustinova et al. (2004) [41], who studied both hemiplegic patient and normal control group of average age less than 50 years.

4. CONCLUSION

It can be concluded from the above studies that the overall stance stability of hemiplegic patient group of age below 50 years is poorer than the age matched control group and such postural instability is much evident in absence of any visual reference. Hence, post-stroke hemiplegic patients bear standing balance deficits compared to age matched control group. However, focusing more attention in the field of stabilometry of hemiplegic patients may help researchers and medical professionals to evaluate and clinically correlate statistically significant COP-based parameters with static balance of hemiplegic patients.

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