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# Quantitative static and dynamic assessment of balance control in stroke patients

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Dear Editor,

We would like to submit the enclosed manuscript entitled " Quantitative static and dynamic assessment of balance control in stroke patients", which we wish to be considered for publication in JOVE.

The work described has not been submitted elsewhere for publication, in whole or in part, and all the authors listed have approved the manuscript that is enclosed.

We proposed a quantitative, clinical balance assessment method suitable for stroke patients with balance disorders and described the details of the whole processing. We believe that this manuscript will make it interesting to general readers of your journal.

Moreover, we appreciate this manuscript could be accepted and in-pressed at the end of this year because the Grant supported this study supposed to be finished in 2019.

Thank you very much for your time and consideration.

Sincerely yours,

**TITLE:**

# Quantitative Static and Dynamic Assessment of Balance Control in Stroke Patients

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**KEYWORDS:**

stroke, static balance assessment, dynamic balance assessment, Berg balance scale, quantitative balance assessment, posturography

**SUMMARY:**

Presented here is a quantitative, clinical balance assessment method suitable for stroke patients with balance disorders.

**ABSTRACT:**

In patients with stroke, damage to the central nervous system (CNS) can affect the postural stability and increase the risk of falling. Therefore, accurately assessing the balance is important to understand the type, extent, and causes of balance deficit, and to identify individualized interventions. Clinical assessment methods for balance function can be broadly divided into observation, scale assessment, and balance instrument testing. Here, a clinical protocol is presented for static and dynamic balance assessment in stroke patients, which includes three semiquantitative balance function scale assessments (i.e., Berg Balance Scale, Timed Up and Go Test, and Fugl-Meyer Assessment) and three quantitative instrumental balance evaluation (i.e., Stability Assessment Module, Proprioceptive Assessment Module, and Limit of Stability Module). It is recommended that clinicians consider the use of both classic clinical balance scales and instrumental balance measurements when assessing stroke patients to improve the accuracy of assessments, leading to a better individualized treatment plan.

**INTRODUCTION:**

The human body can maintain posture stability under various conditions, including internal and external disturbances[1]. Balance relies on sensory input, integration of the central nervous system (CNS), and motor control[2]. In patients with stroke, damage to the CNS can affect the ability to maintain balance[3]. Postural instability is an important risk factor for falls[4]. Approximately 70% of patients experience a fall in the first year after stroke, often with serious consequences, such as hip fracture in elderly patients[5,6]. Moreover, previous studies have shown that postural sway and increased motor response time to visual stimuli are associated with an increased fall risk[7,8]. Because strokes have a substantial impact on mobility, accurate qualitative and quantitative balance assessment is important for understanding the type, extent, cause of balance deficit, as well as guidance for individualized interventions and appropriate gait aids[9].

Clinical assessment methods for balance can be broadly divided into observation, scale assessment, and balance instrument testing. Observation methods (e.g., the Romberg test[10]) are only used as a rough screening for patients with balance dysfunction due to their strong subjectivity. Many balance function scales are commonly used in clinical practice because of their ease-of-use, economy, and relative quantification. These include the Tinetti scale[11], Berg Balance Scale (BBS)[12], Fugl-Meyer Assessment (FMA)[13], and Timed Up and Go (TUG) test[12]. These clinical tests are not suitable for determining the fall risk in patients with significant balance disorders, because they are subjective assessments and often are not able to substantiate the self-reported balance problems experienced by individuals with mild-to-moderate balance problems[14]. Balance instrument testing, a posturography technique, is a useful tool to quantitatively measure the static and dynamic balance function and require

balance evaluation systems, such as a force tilting board with pressure sensors, computers, monitors, balance control panels, and professional balance analysis software. These approaches can assess the degree, type, or cause of the balance damage simultaneously by accurately measuring the center of gravity (COG) and postural sway, thereby precisely and objectively reflecting the patient's balance function. Balance instrument testing can detect subtle differences or damages that the clinical scales cannot. This can be used to overcome the ceiling effect of the scale assessment. With the increasing application of posturography techniques and popularization of computers, it is necessary to promote objective/quantitative balance assessment into clinical practice.

This article describes a clinical balance assessment method that includes standard clinical balance scales and three-module instrument objective balance assessment for stroke patients with balance disorders. A comparison of the results of the clinical assessment scales versus the instrumental balance assessment, is presented to show the advantages of instrumental balance assessment, especially for stroke patients with mild balance disorders. This protocol can help health professionals achieve accurate evaluation to guide clinical treatments. The representative posturography instrument (see **Table of Materials**) used in this protocol has been validated for dynamic assessment and statistic assessment in previous studies[15-17]. The system, which is composed of a screen monitor and a tilting board where the patients stand, can be used for evaluating the visual, auditory, and proprioceptive feedback of the patients.

**PROTOCOL:**

The clinical project was approved by the Medical Ethics Association of the Fifth Affiliated Hospital of Guangzhou Medical University and has been registered at the China Clinical Trial Registration Center (No. ChiCTR1900021291) with the title "The mechanism and effect of Pro-kin system training on static and dynamic balance".

**1. Participant recruitment**

1.1. Include patients with brain hemorrhage or infarction confirmed by magnetic resonance imaging (MRI) or computerized tomography (CT); more than one month onset of stroke; stable vital signs of life; Mini-mental State Examination (MMSE)[18] score of >10 points; able to stand alone for more than 1 min; able to walk 6 m with or without walking aids, that are able to cooperate with the whole assessment protocol.

1.2. Exclude any patients with any medical condition that would prevent them from following the protocol.

1.3. Obtain written informed consent from each patient before their participation.

1.4. Gather demographic information (i.e., date of birth, weight, height, past medical history, and any past or current medications) from all the patients.

**2. Clinical scale assessment**

2.1. Conduct the lower extremity subscale of the FMA test[13]. Ask the patient to complete a 7-point subscale (total score of 34 points) for the measurement of motor impairment on reflexes, coordination, and voluntary movements of the paretic leg poststroke. Score the patient. A higher FMA-LE score indicates a better level of motor recovery.

2.2. Conduct the Timed Up and Go (TUG) test[19]. Ask the patient to perform three consecutive TUG trials at a self-selected pace for safety and comfort[20].

2.2.1. Ask the patient to sit in a chair with their arms resting comfortably on their lap and hips positioned on the back of the seat.

2.2.2. Ask the patient to rise from the chair, walk 3 m, turn around, return to the chair, and sit down. The therapist will time the whole process using a stopwatch.

2.2.3. Allow the patient to use assistive devices during the TUG test, if needed. The average recorded time of the three tests is the patient's final score. Score the patient.

2.3. Conduct the BBS test[12] by asking each patient to perform 14 tasks of a 5-point scale (ranging from 0–4) (total score, 56 points). Some examples of these tasks are provided below.

2.3.1. Ask the patient to stand up and try not to use their hands for support.

2.3.2. Ask the patient to stand for 2 min without holding on to anything.

2.3.3. Ask the patient to sit with their arms folded for 2 min.

2.3.4. Ask the patient to sit down.

2.3.5. Ask the patient to transfer one way towards a seat with armrests and one way towards a seat without armrests.

2.3.6. Ask the patient to stand still for 10 s with their eyes closed.

2.3.7. Ask the patient to place their feet together and stand without holding on to anything.

2.3.8. Ask the patient to lift one arm/two arms to 90˚ , and then stretch out his/her fingers and reach forward as far as he/she can. Measure the distance of forward reach with a ruler.

2.3.9. Ask the patient to pick up the shoe/slipper that is placed in front of his/her feet.

2.3.10. Ask the patient to turn and look directly behind over their left shoulder and then their right shoulder.

2.3.11. Ask the patient to turn completely around in a full circle, and then turn a full circle in the other direction.

2.3.12. Ask the patient to place each foot alternately on a step/stool four times.

2.3.13. Ask the patient to place one foot directly in front of the other.

2.3.14. Ask the patient to stand on one leg as long as they can without holding on to anything.

NOTE: Items 2.3.2, 2.3.3, 2.3.6, 2.3.7, and 2.3.14 are classified as static items. All other items are classified as dynamic items. Score the patient. Scores of 0-20 indicate a high risk of falling, scores of 21–40 indicate a medium risk of falling, and scores of 41–56 indicate a low fall risk[9].

## 3. Static and dynamic balance instrument evaluation

### 3.1. Patient preparation

3.1.1. Instruct the patient to take off their shoes and socks and to wear a trunk sensor on the xiphoid. The trunk sensor is a circular signal transmitter used for detecting the inclination of the subject's trunk position (backward forward and mediolateral) and collecting data (**Figure 1** ①).

3.1.2. Explain all the procedures to the patient and then ask the patient to stand barefoot on the support surface (**Figure 1**).

3.1.3 Ask the patient to stand on the fixed tilting board with one foot and then both feet to get used to the tilting board for 2 min (**Figure 1** ②).

NOTE: During the last three testing modules, the tilting board is used to detect the participant's COG in real time with four decelerator pistons that can automatically modify the active resistance of the board as needed in dynamic balance measurements. The surface of the tilting board is divided into eight different areas (S1, S2, S3, S4, S5, S6, S7, and S8) with four axes (A1-A5/ Backward – Forward, A2-A6, A3-A7 /Medium – Lateral, and A4-A8) (**Figure 1** ②), and a built-in computer to accurately calculate swing range of patients during the testing.

### 3.2. Stability assessment

NOTE: The stability assessment is used for assessing the ability to maintain postural stability under static conditions.

3.2.1. Click the **Static Stability Assessment** button to start the Stability Assessment Module. Then, fix the auxiliary testing equipment onto the tilting board to guarantee that the patient's foot is always in the same position among the different modules of the tests (**Figure 1** and **Figure 2B**).

3.2.2. Click the **Reset** button to reset the tilting board.

3.2.3. Instruct the patient to place the medial margin of their both feet against the auxiliary testing equipment and the highest points of the foot arches on the A3 and A7 axis, and then to place their hands at the sides of their body in a natural position (**Figure 2A**,**C**).

3.2.4. Click the **Reset Trunk** button to run the trunk sensor's automatic calibration program.

3.2.5. Click the **Options** button to select the **Sequence Opened eyes/Closed eyes** (**Romberg**) to begin the Romberg Test[10] for either the open or closed eyes test.

3.2.6. Turn the computer monitor to the side to keep it out of the patient's view (**Figure 2**). Then, instruct the patient to stare at the 'marker' in front of them (1.5 m distance between the eyes and the marker) and to stand stable with their feet in a stationary position (**Figure 2A**).

3.2.7. Click the **Start** button and ask the patient to stand stable with their eyes open for 30 s. The program will be terminated automatically.

3.2.8. Click the **Start** button and ask the patient to stand stable with their eyes closed for 30 s. The first 5 s phase of the eyes open/eyes closed balance test is for patient adaptation, whereas the next 25 s phase is for the formal testing and data recording. The program will be automatically terminated.

3.2.9. Click the **Results** button to obtain the report from the built-in software calculations. For the specific calculation formula refer to the user manual (**Figure 2D**).

### 3.3. Proprioceptive assessment

NOTE: Proprioceptive assessment is used to evaluate the postural stability and fine coordination function of lower limbs of stroke subjects.

3.3.1. Click the **Multiaxial Proprioceptive Assessment** button to start the Proprioceptive Assessment Module.

3.3.2. Remove the auxiliary testing equipment from the test tilting board and click the **Reset** button to reset the tilting board.

3.3.3. Ask the patient to get ready into position as shown in **Figure 3** (i.e., sagittal foot spread with hands on the bilateral armrest) and with the individual foot to be tested on the mobile tilting board (i.e., the second metatarsal and midpoint of heel located on the A1–A5 line, and the highest point of the arch placed on the A3 and A7 axis), and the other foot resting on the support surface parallel to the foot being tested (**Figure 3D**).

3.3.4. Click the **Options** button and click off the **Static** buttons for both axes (front-behind and left-right) to get the tilting board into a dynamic state for 3 s. Pay attention to the patient's position in case of falling.

3.3.5. Click the **Soft** button to set the **force absorbers parameter** to **1**.

NOTE: The available levels of the force absorbers range from 1 (the most unstable) to 40 (almost static).

3.3.6. Click the **Variables** to set Limits to "**5°-10°**", **Rounds** (number of circles) to "**3**", and **Test** to "**Compared**" for the left-right compared model. The left-right compared model indicates the left and right foot tracing will be overlapped in the single graph.

3.3.3. Move the computer monitor in front of the patient at their eye level so that the patient can get visual feedback.

3.3.4. Click the **Enable Trunk** button for the red crosser (COG position) to show up, and then click the **Reset Trunk** button.

3.3.6. Click the **Start** button. The pointer of the footboard (blue cross) is shown on the screen and is responsive to the foot's movement (**Figure 3A**,**E**).

3.3.7. Ask the patient to look at the computer screen to get real-time visual feedback and try to control the blue cross. Instruct the patient to touch the red point first and then follow the blue circle line reference for three circles.

3.3.5. Ensure that the right foot moves in clockwise circles (**Figure 3B**) and the left foot in counterclockwise circles (**Figure 3C**). The motion tracking appears red on the screen.

3.3.8. Click the **Results** button. The software will supply different calculations to analyze.

3.4. Limits of stability module

NOTE: This module measures the ability to maintain postural stability under dynamic conditions.

3.4.1. Click the **Limits of Stability** button to start the Limits of Stability Module.

3.4.2. Click the **Reset** button to reset the tilting board.

3.4.3. Turn off the testing tilting board fastener to set the tilting board into stable mode. Then, fix the auxiliary testing equipment on the test tilting board.

3.4.4. Ask the patient to maintain an upright stance with their arms resting by their sides and their feet in a standardized foot position as required in the Stability Assessment Model (see step 3.2.3) (**Figure 2C**).

3.4.5. Position the computer screen directly in front of the patient at eye level. The patient's COG position is displayed on the screen as the blue cross that moves in response to the movements of their body's COG (**Figure 4A**).

3.4.6. Click the **Start** button and then ask the patient to move the blue COG cross by leaning the body away from the midline as quickly and closely as possible to randomly appearing flashing squares (spread in eight directions, A1-A8, **Figure 3B**) at first and then the original midpoint (blue square in the middle). Instruct the patient to reach their maximal lean-out toward each of the eight targets for the entire LOS test setup (**Figure 4B**).

3.4.7. Click the **Results** button. The software will supply different calculations to analyze.

NOTE: If the patient lost their balance while leaning (e.g., they took a step, held something, or shifted their foot position during testing), their feet should be repositioned, and the trial should be repeated.

**4. Data analysis**

4.1. Obtain and record all demographic characteristics and clinical scale assessment data.

4.2. Obtain the results of Static and Dynamic Balance Instrumental evaluation using the software associated with the balance system at the end of each test by click the **Result** button.

NOTE: The most significant data are presented in graphs like those shown in **Figure 5**, **Figure**

**6**, and **Figure 7.** Based on the manual, the major parameters and their meanings are listed in **Table 1**.

4.3. Transfer the data to statistical software for analysis.

**REPRESENTATIVE RESULTS:**

Results from nine stroke patients with balance deficits are shown. The average age of the nine patients recruited in our study was 52.7 years; all of them were male. Four suffered from right hemiplegia. The average FIM-LE, TUG, and BBS values were 23.9 points, 31.8 s, and 46.8 points, respectively. The other demographic characteristics (BMI, stroke type, and onset time) are shown in **Table 2**. Each item score and the total scores of the BBS assessment of each of the nine stroke patients are shown in **Table 3**. The BBS scores of the nine stroke patients were all above 40 and indicated that they all had mild balance deficits. The results of the instrumental balance evaluation are shown in **Table 4**. The results for one representative patient for the stability assessment, proprioceptive assessment, and loss of stability tests are shown in **Figure 5**, **Figure 6**, and **Figure 7**, respectively.

In **Figure 5C**, the results are visually presented over the blue arrow. The values of M-L Standard Deviation (opened eyes and closed eyes), Ellipse Area (opened eyes and closed eyes), and perimeter (opened eyes and closed eyes) show that the patient was in the warning band, based on the manual of the balance system assessment instrument used in this study. The bands were created by examining 1,000 patients. In **Figure 6A**, the results showed that the average tracking error (ATE) in the left and right feet were both below 100%, whereas in **Figure 6B**, the results showed poor performance in the S7 section in the right foot (above 100%). In **Figure 7A**, the results showed that the average Loss of Stability Module (total results) was 42.6% (below 75%), indicating poor performance. Moreover, the results of the Loss of Stability Module in the 1$^{st}$ to 7$^{th}$ objectives were all below 75% and the 5$^{th}$ objective was the lowest at 8.8%.

**FIGURE AND TABLE LEGENDS:**

**Table 1: The major parameters and their meanings for static and dynamic balance evaluation on the instrument.**

**Table 2: The demographic characteristics and clinical assessments of the stroke patients tested.**

**Table 3: The Berg balance scale assessment in stroke patients.**

**Table 4: Static and dynamic instrumental balance evaluations in stroke patients.**

**Figure 1: Setup for instrumental balance assessment.**

**Figure 2: Setup for the Stability Assessment Module.** (**A**) The initial position for the stability assessment. (**B**) The auxiliary testing equipment and the tilting board. (**C**) The foot position on the tilting board. (**D**) The control board for the balance assessment system.

**Figure 3: Setup for the Proprioceptive Assessment Module.** (**A**) The initial position for the Proprioceptive Assessment. (**B**) The right foot moves in clockwise circles. (**C**) The left foot moves in counterclockwise circles. (**D**) The foot position on the tilting board. (**E**) The control board for the balance assessment system.

**Figure 4: The setup for the Limits of Stability module.** (**A**) The initial position for the Limits of Stability. (**B**) The patient is leaning the body away from the midline. (**C**) The control board for the balance assessment system.

**Figure 5: Comparing the stability assessments for patient number 4.** Eyes open vs. eyes closed. (**A**) The basic demographic information and results of the main parameters. (**B**) The tracing trajectory of COP-eyes open (orange) and COP-eyes closed (green). (**C**) Comparison of eyes open and eyes closed data: backward-forward standard deviation (BF), medium-lateral standard deviation (ML), and area and perimeter (PER). The patient's results are over the blue arrow. For every result and both tests (closed eyes, opened eyes) the patient's condition can be determined within the ideal (green), healthy (yellow), or warning (red) band.

**Figure 6: Comparing the proprioceptive assessments for patient number 4.** (**A**) The basic demographic information and results of the main parameters. (**B**) The resulting graph of track errors (%) for the left foot (red bar) and right foot (green bar). (**C**) The resulting graph of force variance (kg) for the left foot (red bar) and right foot (green bar). (**D**) The tracing trajectory of the left foot (orange line). (**E**) The tracing trajectory of the right foot (orange line).

**Figure 7: The limits of stability for patient number 4.** (**A**) The basic demographic information and the results of the main parameters. (**B**) The resulting graph of the A1-A8 loss of stability (LOS) and the tracing trajectory (blue lines) from the COG to the A1-A8 squares in eight directions.

**DISCUSSION:**

Described is a clinical protocol for static and dynamic balance assessment in stroke patients that includes three semiquantitative balance function scale assessments (BBS, TUG, and FMA-LE) and three models of quantitative instrumental balance evaluation (Stability Assessment, Proprioceptive Assessment, and Limit of Stability). The design of this protocol was based on five main points.

First, the BBS is a 14-function-task on a 5-point scale that semiquantitatively assesses static and dynamic balance and the risk of falls through direct observation of a subject's performance[21]. The global score of the BBS is 56 points, where scores of 0–20 represent

balance impairment, 21–40 represent acceptable balance, and 41–56 represent good balance[9]. The BBS was originally designed to assess balance in community-dwelling elderly individuals[21] and became the most commonly used assessment tool in patients with stroke[9] due to its relatively low equipment and space requirements, as well as its reliability and validity[22]. However, the BBS has floor and ceiling effects, suggesting that the BBS might not detect meaningful changes when used to assess patients at either extreme, who have either severe balance impairment or mild impairment[23,24]. The nine stroke patients that participated in this study had mild balance deficits based on their BBS scores. The subjects achieved the highest score (4/4) in most of the BBS tests, except for the test that requires reaching forward with an outstretched arm (i.e., one patient with a score of 2/4, six patients with 3/4, and 2 patients with 4/4). It might be still hard to develop a personal treatment strategy for these kinds of patients with high balance function based on the BBS assessment. The TUG and FMA-LE showed similar results. The quantitative balance instrument evaluation is superior to these alternatives. For example, all nine stroke patients had BBS assessment scores of more than 40 points, suggesting that all the patients had relatively good balance performance. All nine patients scored the maximum number of points (4/4) in the standing-with-eye-closed test, whereas the Average COP.X (mediolateral axis) and Average COP.Y (anteroposterior axis) in the Stability Assessment Module of the instrumental balance evaluation presented various values, from -33–30 for the Average COP. X (mediolateral axis) and from -20–50 for the Average COP.Y (anteroposterior axis). The report from one of the nine patients also showed three items in the warning band in **Figure 5C**. Second, the total score of the BBS assessment could be used to predict the fall risk, in which scores of 0–20 indicate high fall risk, 21–40 indicate medium fall risk, and 41–56 indicate low fall risk[19]. BBS predicts the fall risk by evaluating the patient's overall balance performance under different tasks. Moreover, the BBS test that requires reaching forward with an outstretched arm is supposed to evaluate the stability limits of the clinical functional reach, although Wernick-Robinson and collaborators[25] suggest that the arm displacement test does not fully reflect dynamic balance. In contrast, based on the manual of the instrument used in this study, the Loss of Stability Module parameter describes the maximum angle at which the body can tilt during standing (the maximum forward-backward angle is 12.5° and the maximum medium-lateral angle is 16°), which is an important indicator of the ability to maintain postural stability under static and dynamic conditions, such as during a quiet stance, in response to postural perturbations, or during postural preparation for movements[26]. The Loss of Stability Module test could provide measures of COG movements as a patient intentionally leans toward various positions in space[27]. Ikai et al.[28] suggest that decreased postural stability is a common problem associated with stroke. In this protocol, the main parameter of the Loss of Stability Module assessment is reaction time. Brown et al.[29] demonstrated increased reaction times among stroke patients during various postural tasks, compared to healthy older adults. Moreover, the Loss of Stability Module module in this protocol evaluates the maximal lean of eight objectives around the COP, whereas the BBS assessment evaluates the forward direction alone.

Third, the sensory systems related to balance maintenance (i.e., the proprioceptive, visual,

and vestibular systems) play distinct roles. The instrumental balance evaluation also presents advantages for determining the cause of the balance disorder compared to the BBS assessment. In the stability assessment module of this protocol, the eye-closed exam was used to reduce or remove the effects of vision, thereby measuring the other major sensor systems (i.e., proprioception and vestibular systems) related to balance. Moreover, proprioception damage is a common symptom after stroke, and it is also an important factor that restricts the balance of patients with hemiplegia[30]. The proprioceptive assessment module in this protocol was intended to target this specifically. The purpose of the proprioceptive assessment module is to provide the patient with an objective assessment of the proprioceptive sensitivity of the patient's foot. This test module not only shows the overall foot sensitivity assessment, but also the sectorial assessment. For example, **Figure 6** shows that the ATE of both feet (32% left foot and 42% right foot), whereas the worst performance in the S7 section occurred in the right foot. In addition, stroke affects the coordination of various systems in posture control. The prospective module in this protocol can also be used to indirectly reflect the fine coordination function of lower limbs in stroke patients.

Fourth, the bilateral lower limbs were required for assessment in our instrumental balance assessment protocol for stroke patients, which is different from the BBS assessment. In BBS assessment processing, the choices of which leg to stand on or how far to reach are left to the subject. So, for the patient with hemiplegia after stroke, the BBS assessment score might not accurately present the effect of the hemiplegic side on the balance deficit.

Fifth, the other two clinical balance assessments we used in this protocol are believed to evaluate the clinical general walking ability (TUG) and to assess the motor recovery in stroke patients (FMA-LE)[31].

During the instrument balance assessment, two important points about troubleshooting must be pointed out. First, during the tests on the mobile platform the physical therapist should very carefully observe the patient's perceptual conditions and the movement of the system to avoid accidental injuries. Second, a physical therapist must stand behind the subject to prevent falls during the whole testing process.

This study has some limitations. First, the data represent only nine male stroke patients. However, these nine stroke patients all showed mild balance deficits based on the BBS scales, and this protocol obtained more detailed data, showing the advantages of instrumental balance assessment. More stroke patients with moderate to severe balance deficits must be recruited to investigate the prospects of instrumental balance assessment in future study and therapy. Second, previous studies have shown that both gender and age have effects on balance ability. For example, with age, posture balance decreases, thus increasing the risk of falling down. Furthermore, women are more affected than men[32]. However, because this study is mainly a methodological demonstration of instrumental balance assessment methods,

it only included male subjects and a relatively large age span (37–67 years old). Future research needs to include female subjects and an age hierarchy to expand the clinical application of this assessment. Third, the cost of the balance assessment instrument used in the study is relatively high, which might limit its clinical use, but the study objective is to present the methodology. A large number of less expensive, similar balance assessment instruments based on posturography[31] could be obtained for clinical practice.

In conclusion, it is recommended that clinicians consider the use of both classic clinical balance scales and balance instrumental measurement in clinical practice for patients after stroke, which could improve the accuracy of assessment and thereby enhance individualized treatment plans.

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**DISCLOSURES:**

The authors have nothing to disclose.

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Figure 1

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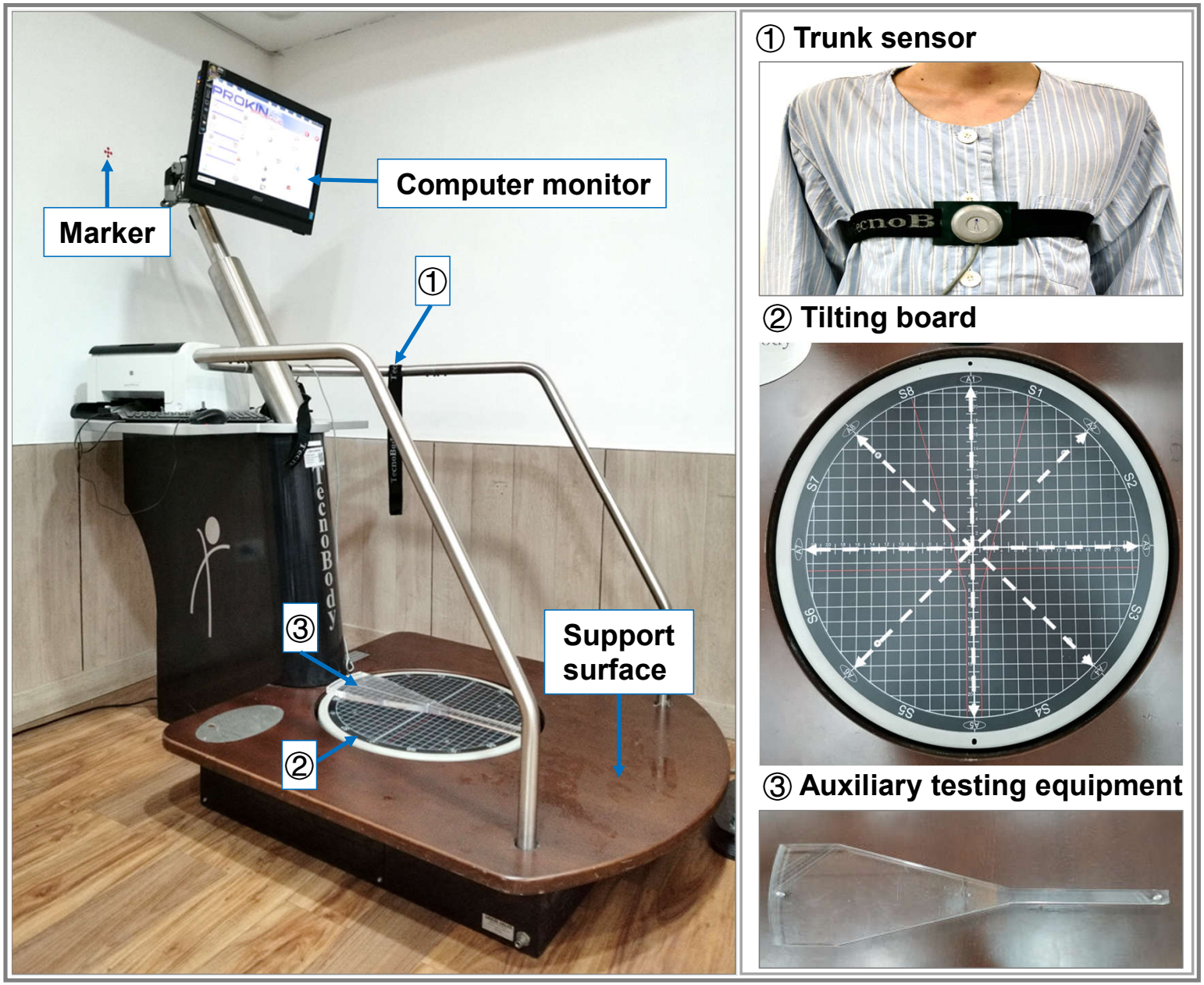

Figure 2

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Figure 3

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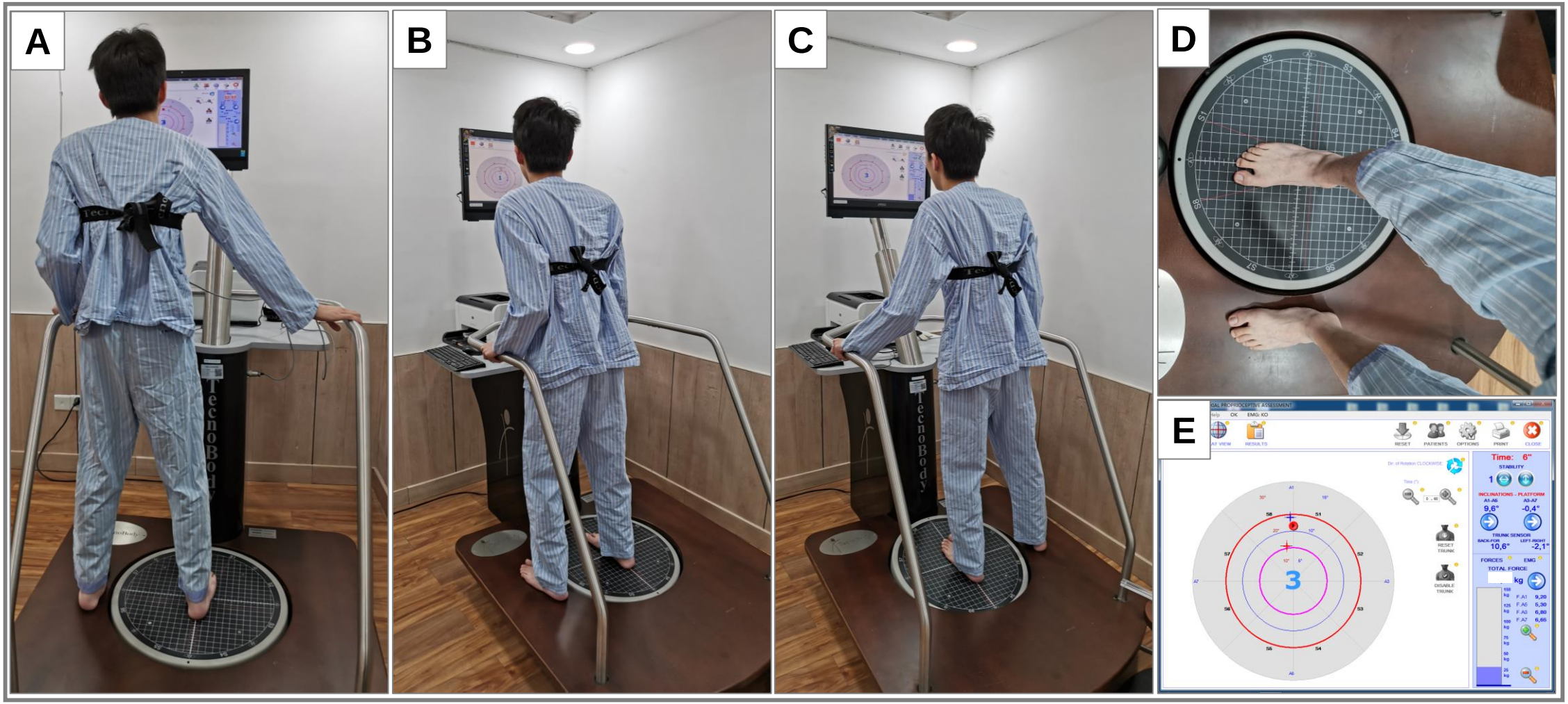

Figure 4

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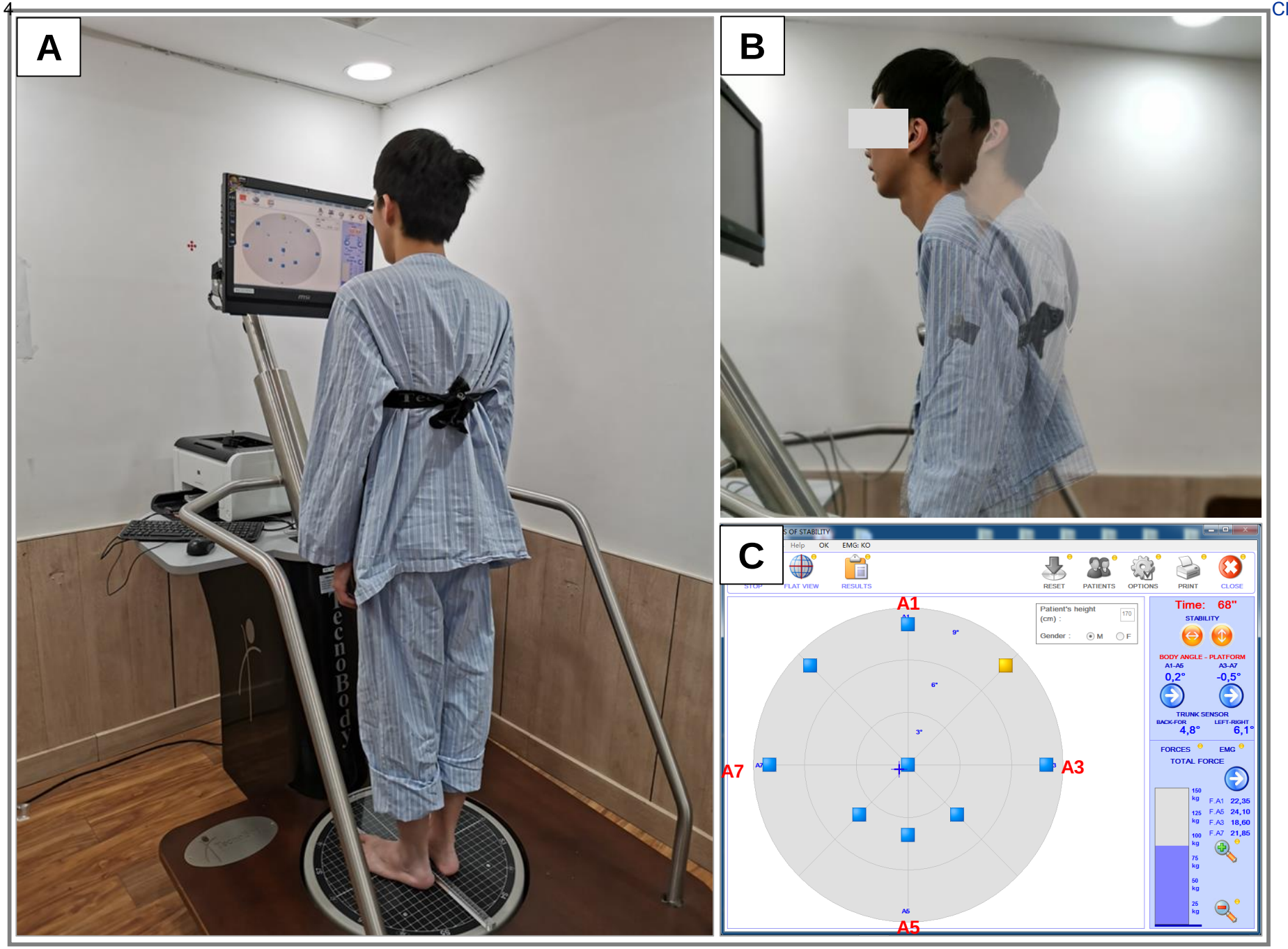

Figure 5

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**Pro-Kin: STABILOMETRY-ASSESSMENT**

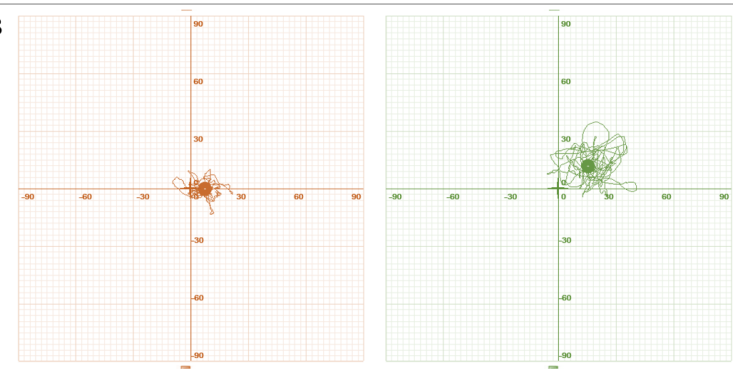
**A**

| | | | | | |
|---|---|---|---|---|---|
| Patient: XXX | | Axis-Points(1) : A1-01 | | Stability | 1 |
| Date/Time: 25/07/2019 13: 20 | Pos: A | Axis-Points(2) : A1-01 | | ML | Static |
| Position: Stabilometry | Opened Eyes | Axis-Points(3) : A1-01 | | BF | Static |
| Weight(kg)/Height(cm): 54/173 | | | | | |
| Time: | 30" on 30" | Average C.o.P.X: | 7 | Average C.oP.Y: | 0 |
| F-B Standard Deviation: | 4 | M-L Standard Deviation: | 5 | Average F-B Speed(mm/sec.): | 12 |
| Average M-L Speed(mm/sec): | 13 | Ellipse Area(mm²): | 355 | Perimeter(mm): | 562 |
| Trunk Tot. St. Dev: | 3.67° | Trunk BF St.Dev.: | 2.22° | Trunk ML St. Dev.: | 2.92° |

| | | | | | |
|---|---|---|---|---|---|
| Patient: XXX | | Axis-Points(1) : A1-01 | | Stability | 1 |
| Date/Time: 25/07/2019 13: 20 | Pos: A | Axis-Points(2) : A1-01 | | ML | Static |
| Position: Stabilometry | Closed Eyes | Axis-Points(3) : A1-01 | | BF | Static |
| Weight(kg)/Height(cm): 54/173 | | | | | |
| Time: | 30" on 30" | Average C.o.P.X: | 15 | Average C.oP.Y: | 12 |
| F-B Standard Deviation: | 7 | M-L Standard Deviation: | 9 | Average F-B Speed(mm/sec.): | 30 |
| Average M-L Speed(mm/sec): | 26 | Ellipse Area(mm²): | 1183 | Perimeter(mm): | 1287 |
| Trunk Tot. St. Dev: | 4.12° | Trunk BF St.Dev.: | 0.60° | Trunk ML St. Dev.: | 4.08° |

E.C/E.O Area Ratio: 333 *110-250 E.C/E.O Perimeter Ratio: 333 *110-250

**B**




**C**

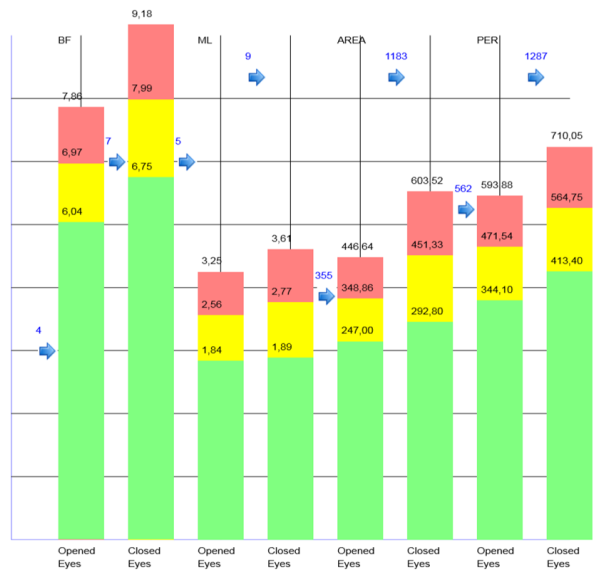


Figure 6

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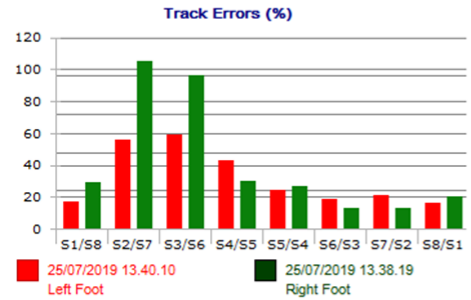
# Pro-Kin: COMPARED PROPRIOCEPTIVE ASSESSMENT

**A**

| | | | | | |
|---|---|---|---|---|---|
| Patient: XXX<br>Date/Time: 25/07/2019 13: 40 Pos: A<br>Position: Left foot<br>Weight(kg)/Height(cm): 54/173 | | Axis-Points(1) : A1-01<br>Axis-Points(2) : A1-01<br>Axis-Points(3) : A1-01 | | Stability 1<br>ML Dynamic<br>BF Dynamic | |
| Time: | 63" on 120" | Rounds Number: | 3 | Stability index : | 1.30° |
| Average Track Error(A.T.E.): | 32%*0%<=x<=35% F1 | Average Force Variance(AFV): | 1.3kg | Trunk Tot.St.Dev.: | 11.31° |
| Trunk BF St.Dev.: | 9.89° | Trunk ML St. Dev.: | 5.48° | | |
| Patient: XXX<br>Date/Time: 25/07/2019 13: 38 Pos: A<br>Position: Right foot<br>Weight(kg)/Height(cm): 54/173 | | Axis-Points(1) : A1-01<br>Axis-Points(2) : A1-01<br>Axis-Points(3) : A1-01 | | Stability 1<br>ML Dynamic<br>BF Dynamic | |
| Time: | 26" on 120" | Rounds Number: | 3 | Stability index : | 0.12° |
| Average Track Error(A.T.E.): | 42%*35%<=x<=100%F2 | Average Force Variance(AFV): | 1.4kg | Trunk Tot.St.Dev.: | 4.20° |
| Trunk BF St.Dev.: | 2.78° | Trunk ML St. Dev.: | 3.15° | | |

**B**

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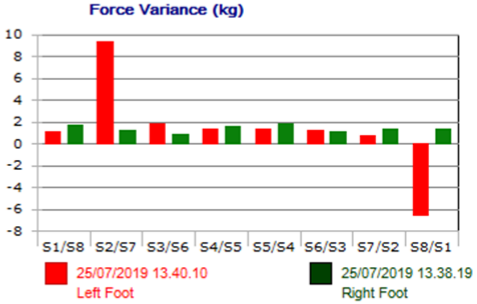


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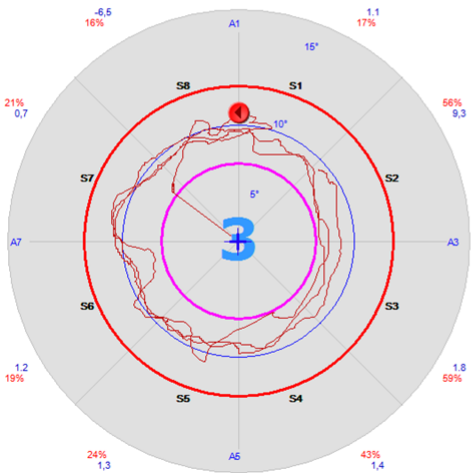


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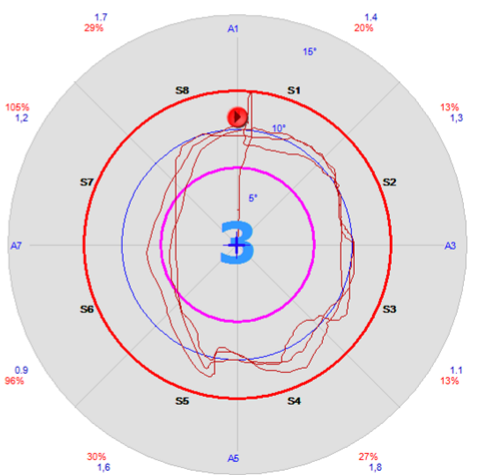

Figure 7

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# Pro-Kin: LIMITS OF STABILITY

**A**

Patient: XXX
Date/Time: 25/07/2019 13: 27 Pos: A
Position: Bipedal
Weight(kg)/Height(cm): 54/173

Axis-Points(1) : A1-01
Axis-Points(2) : A1-01
Axis-Points(3) : A1-01

| | |
|---|---|
| Stability | 1 |
| ML | Static |
| BF | Static |

| | | | | | |
|---|---|---|---|---|---|
| Time: | 80" on 180" | 1st objective : | 48.8% | 2nd objective : | 55.7% |
| 3rd objective : | 45.0% | 4th objective : | 44.2% | 5th objective : | 8.8% |
| 6th objective : | 24.7% | 7th objective : | 37.5% | 8th objective : | 76.0% |
| Total results : | 42.6% *75.0%-100.0% | | | | |

**B**

Results

Patient's height (cm) : 173

Gender : (•) M ( ) F

| | |
|---|---|
| 1st objective | 48,8% |
| 2nd objective | 55,7% |
| 3rd objective | 45,0% |
| 4th objective | 44,2% |
| 5th objective | 8,8% |
| 6th objective | 24,7% |
| 7th objective | 37,5% |
| 8th objective | 76,0% |
| Total results | 42,6% |

Ref. 75,0% - 100,0%

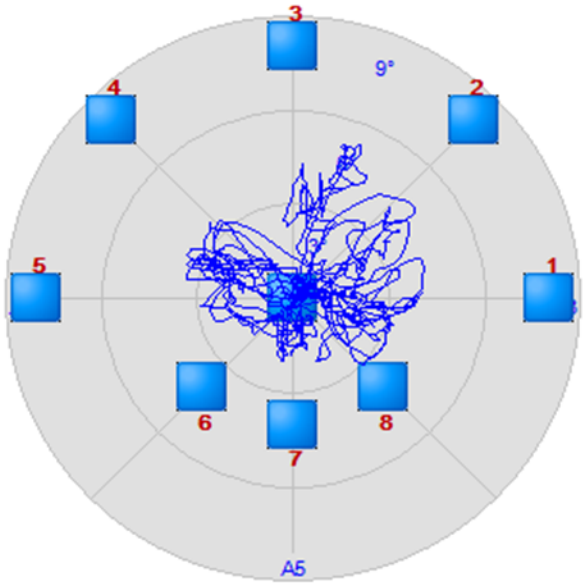

**Table 1 The major paramet**

| Paranmeter |
| --- |
| Average COP.X |
| Average COP.Y |
| Average F-B Speed |
| Average M-L Speed |
| Romberg Test-Perimeter Ratio C.E./O.E. |
| Romberg Test–Area Ratio C.E./O.E. |
| Average Track Error, ATE |
| Average Force Variance |
| Stability Index |
| Reaction time of LOS |
| Results of LOS |
| Average of LOS |

**Notes: COP, Center of Pres**
**second; C.E, closed eyes; O**

**ters and their meanings of static and dynamic balance instrument evaluation.**

| Meaning |
| --- |
| the average COP on the X-axis/medio-lateral axis (UOM[mm]) |
| the average of COP on the Y-axis/ anterior-posterior axis (UOM [mm]) |
| the average speed of forward-backward movements (UOM [mm/sec]) |
| the average speed of medium-lateral movements (UOM ([mm/sec]) |
| the ratio of perimeter between closed eyes test and opened eyes test. Perimeter represents the math sum of all segments point to point created during the test. The range of the ratio (110–250) in healthy participants as reference based on the manual of manufacture. |
| the ratio of the perimeter between closed eyes and opened eyes tests. The area represents 95% of the area developed by COP movement. The range of the ratio (110–250) in healthy participants as reference based on the manual of manufacture. |
| during the proprioceptive assessment module, the average value of differences between the red line being plotted by the foot and the blue line, which is perfectly round, provides a proprioceptive sensitivity index of the foot being tested. All the ATE index values ranging between zero and 35% are considered as very good regarding subtle proprioceptive control; ATE index values of 35–100% are considered sufficient; and scores above 100% indicate some problem with proprioceptive control, which may need further evaluation and investigation. |
| the average of applied loaded in eight fundamental sectors on the tilting board during test. |
| the index is a dispersion index in relation with the waited result (the references axis vertical or horizontal) during the Proprioceptive Assessment test. |
| the time the patient took to reach their maximal lean-out toward each of the 8 targets in the LOS test. |
| the values on eight objectives were derived from the amount of on-axis movement of the COG relative to off-axis COG movement and is expressed as a percentage of the total on-axis movement. |
| the average value of the results on the eight objectives. |

**sure; UOM, unit of measurment; F-B, forward-backward; M-L, mm, millimetre; sec, .E, opened eyes; ATE, Average Track Error; LOS, limits of stability;**

**Table 2 The demographic characteristics and clinical assessments of stroke patients.**

| Patient No. | Gender | Age (year) | Height (cm) | Weight (kilogram) | BMI | Stroke type | Onset time (months) |
|---|---|---|---|---|---|---|---|
| **NO.1** | male | 43 | 173 | 80 | 27 | Infarction | 7 |
| **NO.2** | male | 62 | 168 | 61 | 22 | Infarction | 34 |
| **NO.3** | male | 56 | 163 | 57 | 21 | Hemorrhage | 7 |
| **NO.4** | male | 37 | 173 | 54 | 18 | Hemorrhage | 3 |
| **NO.5** | male | 41 | 170 | 76 | 26 | Hemorrhage | 17 |
| **NO.6** | male | 63 | 173 | 76 | 25 | Hemorrhage | 3 |
| **NO.7** | male | 58 | 177 | 80 | 26 | Hemorrhage | 71 |
| **NO.8** | male | 47 | 162 | 60 | 23 | Hemorrhage | 1 |
| **NO.9** | male | 67 | 167 | 63 | 23 | Hemorrhage | 1 |
| Mean±SD | | 52.7.7±10..3 | | | 23.4±2.7 | | 16.0±21.9 |

**Notes:** BMI, Body Mass Index; FIM-LE, lower extremity Fugl-Meyer Assessment; BBS, Berg Balance Sca

| Affected hemisphere | FIM-LE | TUG (second) | BBS |
|---|---|---|---|
| Right | 27 | 23 | 48 |
| Left | 19 | 34 | 45 |
| Right | 13 | 60 | 43 |
| Left | 23 | 28 | 48 |
| Left | 20 | 31 | 45 |
| Left | 23 | 45 | 43 |
| Left | 34 | 22 | 51 |
| Right | 23 | 28 | 48 |
| Right | 33 | 15 | 50 |
| | 23.9±6.3 | 31.8±12.7 | 46.8±2.7 |

le.

**Table 3 The Berg balance scale assessment in stroke patients.**

| Item \ Participant NO. | NO.1 | NO.2 | NO.3 | NO.4 | NO.5 | NO.6 | NO.7 | NO.8 | NO.9 |
|---|---|---|---|---|---|---|---|---|---|
| Sitting to standing | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Standing unsupported | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Sitting unsupported | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Standing to sitting | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Transfers | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Standing with eyes closed | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Standing with feet together | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Reaching forward with outstretched | 4 | 3 | 3 | 3 | 2 | 3 | 4 | 3 | 3 |
| Retrieving object from floor | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 |
| Turning to look behind | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Turning 360 degrees | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 4 |
| Placing alternate foot on stool | 3 | 1 | 0 | 3 | 2 | 0 | 4 | 4 | 4 |
| Standing with one foot in front | 2 | 2 | 2 | 3 | 2 | 1 | 2 | 2 | 2 |
| Standing on one foot | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Total Score (Maximum = 56) | 48 | 45 | 43 | 48 | 45 | 43 | 51 | 48 | 50 |

**Notes:** Total scores of 0 to 20 indicate high fall risk, 21 to 40 indicate medium fall risk, and 41 to 56 indicate high fall risk.

**Table 4 Static and dynamic instrumental balance evaluations in stroke patients.**

| Parameters \ Participant NO. | NO.1 | NO.2 | NO.3 | NO.4 |
|---|---|---|---|---|
| **STABILITY ASSESSMENT** | | | | |
| Average COP.X (E.C/E.O) | -9/-6 | 30/26 | -23/-34 | 15/7 |
| Average COP.Y (E.C/E.O) | -6/-11 | -9/-17 | -5/2 | 12/0 |
| Average F-B Speed (E.C/E.O) (mm/sec.) | 22/9 | 38/17 | 16/9 | 30/12 |
| Average M-L Speed (E.C/E.O) (mm/sec.) | 22/12 | 17/9 | 15/10 | 26/13 |
| Romberg Test (Ref. 110-250) | | | | |
| E.C/E.O Perimeter Ratio | 197 | 210 | 155 | 229 |
| E.C/E.O Area Ratio | 191 | 152 | 194 | 333 |
| **PROPRIOCEPTIVE ASSESSMENT** | | | | |
| Average Track Error (Left/Right) (%) | 86/159 | 114/49 | 133/183 | 32/42 |
| Average Force Variance (Left/Right) (Kg) | 5.5/5.1 | 0.4/2.8 | 4.8/3.7 | 1.3/1.4 |
| Stability Index (Left/Right) | 2.98/3.38 | 3.11/1.75 | 3.64/3.91 | 1.3/0.12 |
| **LIMITS OF STABILITY (LOS)** | | | | |
| Response Time (sec) | 77 | 84 | 113 | 80 |
| Average of LOS (%) | 28.7 | 29.7 | 11.3 | 42.6 |

**Notes:** Average COP.X, average of Center of Pressure (COP) on X-axis; Average COP.Y, average of Cen
E.O, eye open; Average F-B Speed, average speed of forward-backward; Average M-L Speed, average spe
is the range of ratio when the patient is healthy.

| NO.5 | NO.6 | NO.7 | NO.8 | NO.9 |
|---|---|---|---|---|
| 29/27 | 11/8 | 13/10 | -33/-27 | 23/18 |
| 11/5 | -20/-21 | -13/19 | -15/-7 | 50/44 |
| 19/15 | 23/10 | 9/10 | 16/8 | 32/14 |
| 14/13 | 15/10 | 8/9 | 19/11 | 14/7 |
| 113 | 189 | 89 | 181 | 210 |
| 112 | 406 | 71 | 335 | 152 |
| 81/49 | 44/45 | 43/40 | 59/98 | 38/69 |
| 3.5/2.4 | 3.7/4.8 | 4.1/3.0 | 3.7/3.9 | 2.0/2.3 |
| 1.9/1.84 | 1.14/1.58 | 1.36/2.22 | 1.72/2.51 | 1.58/7.5 |
| 78 | 86 | 101 | 83 | 86 |
| 38.2 | 70.9 | 40.3 | 41.9 | 47.1 |

ıter of Pressure (COP) on Y-axis; COP, Center of Pressure; E.C, eye closed; ɛed of medium-lateral; Ref., reference; The references 110-250 show which

| Name of Material/ Equipment | Company | Catalog Number | Comments/Description |
|---|---|---|---|
| Electric Lifting Bed | Guangzhou Yikang Med | YK-8000 | Required for Fugl-Meyer assessment |
| Percussion hammer | ICARE-MEDICAL Co., | CRT-104 | Required for Fugl-Meyer assessment |
| Prokin Balance System | Tecnobody .S.r.l, Italy | ProKin 252 | Balance evaluation and training system |
| Ruler | M&G Chenguang Statio | AHT99112 | Required for Berg Balance Scale assessment |
| Stopwatch | 95,Shenzhen Junsd Indu | JS-306 | Required for Berg Balance Scale assessment |

**RE: JoVE60884 R2: Manuscript Revision Required**

**Dear Editor,**

**Thanks for the editor board interested in this manuscript (ID: JoVE60884), hard work of formatting and gave us the third opportunity to address editor's comments. All points in the comments have been addressed in the manuscript R2. The manuscript was kept with marks in Microsoft Word. Please also see the attachment of response to editor's comments.**

**We would like to submit the 2nd revised version for your consideration to be published soon.**

**Yours sincerely,**

**Junjie Liang**

**Editorial comments:**

**1. The editor has formatted the manuscript to match the journal's style. Please retain and use the attached file for revision.**

Response to the comments: Thank you for your great and hard work.

**2. Please address all the specific comments marked in the manuscript.**

Response to the comments: Thank you for the commons and advises. We revised our manuscript based on your each common. Please find all the details in our R2 version.

**3. Please ensure that the highlight is no more than 2.75 pages including headings and spacings.**

Response to the comments: Thank you for editor's reminding. The heighted of this manuscript-R2 is no more than 2.75 pages.

**4. Please proofread the manuscript well before submitting the revision.**

Response to the comments: Thank you for editor's reminding. We checked the grammar before submission.

**Reviewer #1:**

Manuscript Summary:

This revised manuscript describes a protocol used to assess various aspects of balance in a small number of fairly high functioning individuals who have experienced a stroke. As in my original review, I find it unclear what the described work adds to previous more detailed descriptions of post-stroke balance.

Major Concerns:

1. Overall, this manuscript appears to include 3 well established clinical measures of balance, and

3 tests of postural balance that directly follow the manual of a commercially available device. It is unclear whether the protocol described in the text is anything more than a description of methods previously developed by others.

Response to the comments: Thank you for reviewer's comments. JOVE is a methods journal and our paper is supposed to be methodology present. So we focus more on the features of the instrumental balance assessment we used in our protocol. Moreover, we also presented the advantage of instrumental balance assessments on mild balance injured stroke patients than BBS (please see our Discussion part).

2. Likely as a result of the point above, the metrics derived from the commercially available device are not clearly described or justified. Instead, statements such as "…software will supply different calculations…" are made. The validity or usefulness of such metrics cannot be judged. Similarly, the choice of many testing parameters is not justified (e.g. "set the force absorbers parameter to 1" (line 270)).

Response to the comments: Thank you for reviewer's comments. The equipment （Prokin balance system）has been used in many previous studies (please see the reference part). We think the validity and usefulness of this equipment are confirmed.

3. In the Introduction the authors state that they "present the results of a comparison between our instrumented balance assessment, BBS, and two other clinical balance scales…" (lines 99-100). It does not appear to me that any formal type of such comparison is presented.

Response to the comments: Thank you for reviewer's comments. We explained the differences in five main points in the Discussion Part. Please find the details from line 413 to 479.

Minor Concerns:

1. I previously requested that the authors explicitly link postural stability to post-stroke fall risk in the Introduction. The authors have added a sentence that makes this link (lines 64-65), but justify

this sentence by citing a reference that did not actually measure fall risk. A more appropriate reference should be used.

Response to the comments: Thank you for reviewer's comments. We added more details to explain the increased fall risk after stroke.

**2. Is the mentioned "trunk sensor" part of the Prokin Balance System?**

Response to the comments: Thank you for the commons. Yes, the "trunk sensor "is the one of the components belonging to the Prokin balance system.

**3. The description of the axes on lines 212-213 is confusing.**

Response to the comments: Thank you for reviewer's comments. We changed one of the figures of Figure 1 to show more clearly about axes.

4. It is not clear whether the "proprioceptive assessment" will truly assess proprioception, as it seems that motor function would dramatically affect task performance irrespective of proprioceptive function.

Response to the comments: Thank you for reviewer's comments. We rewrote this part and added more details of " Proprioceptive assessment is used to evaluate postural stability and fine coordination function of lower limbs of stroke subjects."

5. In the Data Analysis section, it would helpful to state which metric comes from which test(s).

Response to the comments: Thank you for reviewer's comments. We made a new table to show the parameters and the figures already showed the parameters from different module.

6. The statemeASnt on lines 350-351 that the "references 110-250 show the range of ratio…" is still unclear.

Response to the comments: Thank you for the commons. We have rewritten the sentence as “The range of the ratio (110–250) in healthy participants as reference based on the manual of manufacture.”

7. Some figures or figure legends appear to be mislabeled.

Response to the comments: Thank you for reviewer’s comments. We checked the legends.

8. As mentioned in my previous review, Line 485 states that a BBS score of 41-56 indicates high fall risk. I think this should be low fall risk.

Response to the comments: Thank you for reviewer’s comments. We corrected this part.

9. A very unusual definition of "reaction time" is used, and probably cannot be fairly compared with prior results.

Response to the comments: Thank you for reviewer’s comments. Reaction time is used as the main parameter of the LOS assessment. We are not sure what you mean? Please give us more hits.

**Reviewer #2:**

To the Authors,

The Authors have addressed my concerns from the original submission, and in doing so have much improved the paper. I have several remaining minor concerns regarding the Introduction and Methods, which are detailed in my comments below.

**1. I am still unclear as to the axis labelling system. Would it be possible to label the axes on Figure 1 for clarity?**

Response to the comments: Thank you for the commons. We already labeled the axes on the Figure1 ② to state more clearly.

**2. When describing the variables, there are still many abbreviations used, as well as 'x' and**

**'y' to refer to mediolateral and antero-posterior. This section, as well as the results, would be much easier to follow if the full terms were written out, and mediolateral and antero-posterior used instead of 'x' and 'y'.**

Response to the comments: Thank you for the commons. We have changed "X" and "Y" into "mediolateral axis" and "antero-posterior axis".

**3. Lines 350, 355: I am unclear as to the meaning of 'the references 110-250' and 'the range of the ratio (110-250)'.**

Response to the comments: Thank you for the commons. We have rewritten the sentence as "The range of the ratio (110–250) in healthy participants as reference based on the manual of manufacture."

**4. Lines 366-367: The description of this variable does not imply variance. Please clarify.**

Response to the comments: Thank you for the commons. This parameter is the prokin built-in parameters.

**5 Lines 369-370: The description of this variable is unclear - terms like 'the expected value' and 'reference' are somewhat ambiguous.**

Response to the comments: Thank you for the commons. We rewrote the definition of stability index as follow: "the index is a dispersion index in relation with the waited result (the references axis vertical or horizontal) during the Proprioceptive Assessment test."

6. **The contributions of the study have become clearer in the Discussion. To further support the Discussion, a brief sentence or two could be added to the existing final paragraph of the Introduction, to explicitly state that the results of the protocol could be used to guide clinical strategy, through the integration of multiple assessments targeting different aspects/outcomes related to balance. Something along these lines would clearly identify the benefit of this protocol, and connect to the Discussion.**

Response to the comments: Thank you for the commons and advices. We added some details at the end of the final paragraph of the introduction as follow: "With the increasing application of posturography techniques and the popularization of computers, it is necessary to promote objective/quantitative balance assessment into clinical practice. Here, we propose a clinical balance assessment methodology, which includes standard clinical balance scales and three-module instrument objective balance assessment for stroke patients with balance disorders. Moreover, by comparing the results of clinical assessment scales and instrumental balance assessment, the advantages of instrumental balance assessment are present, especially for stroke patients with mild balance disorders. Our protocol could help health professionals to achieve accurate evaluation, which would guide the clinical strategy."