# Stance Phase Kinematics in Ankle Joint during Ambulation on Uneven Surface: A Comparison between Stroke Survivors and Typical Adults

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## *ABSTRACT*

***Purpose:*** *Gait impairment is a common disability among stroke survivors and is a known risk factor of falls. Outdoor ambulation is essential for everyone, even for basic activities of daily living, but routine assessment of stroke survivors concentrates mainly on indoor ambulation and function. This study is an attempt to document gait parameters in stroke survivors and typical adults during outdoor ambulation.*

***Method:*** *For this prospective pilot study, 7 chronic stroke survivors and 7 age-matched typical adults were recruited by convenience. Measurements were taken of their ankle and subtalar joint angles during various phases of gait, using video analysing software, Kinovea 0.8.15.*

***Results:*** *Large differences in range of motion in the ankle and subtalar joints were noticed between stroke survivors and typical adults during ambulation on various surfaces. During ambulation on a firm surface, plantar flexion range of motion at the ankle was greater at initial contact and mid-stance, whereas on pebbled surfaces vast differences could be seen on initial contact and mid-stance.*

***Conclusion and Implications:*** *Significant stance phase deviations are evident in stroke survivors during ambulation on uneven terrain. This may be a risk for falls and musculoskeletal degeneration. Although definitive conclusions cannot be drawn due to the small sample size, these findings indicate a need for considering outdoor gait evaluation in routine practice in the community. Mobility correlates highly with quality of life and meaningful strategies to adopt safe ambulation methods can be developed only with proper evaluation methods.*

***Key words:*** *joint kinematics, uneven walking, gait alterations, uneven terrain, outdoor ambulation*

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# INTRODUCTION

Locomotor impairment is a common disability in stroke survivors and is a known risk factor of fall (Jaffe et al, 2004). Navigation of uneven terrain is essential for residents of rural regions in much of the developing world, even for basic activities of daily living (BADL) as evidenced by anecdotal and observational accounts. Literature suggests that kinematic and kinetic variables are altered during uneven terrain ambulation; hence increased biomechanical adaptations are required. During outdoor ambulation, stroke survivors are exposed to additional risk factors of fall, due to compromised ability to step over objects and decreased endurance (Medifocus Guidebook On Stroke Rehabilitation, 2010). These factors can result in enforced confinement to the house which can negatively impact their quality of life (QOL).

The International Classification of Functioning, Disability, and Health (ICF) lists walking on different surfaces in the brief core set for stroke. This underpins the importance of outdoor ambulation.

## Objective

Stance phase control and stability are essential for uneven surface ambulation. It is hypothesised that stroke survivors may have difficulty with distal joint stability and control. However, gait parameters during uneven surface ambulation have not been adequately described in literature. This study is an attempt to evaluate kinematic gait parameters of the ankle and foot in stroke survivors, in comparison to typical adults.

# METHOD

## Study Design

Methodological descriptions of this observational exploratory study followed the STROBE guidelines with an objective to compare kinematic gait characteristics between stroke survivors and typical adults during ambulation on level, pebbled and sandy surfaces.

## Study Setting

The study setting was a simulated laboratory with a level walkway measuring 10 metres and a raised platform of pebbles and sand measuring 10×3 m, constructed to mimic the terrains commonly encountered in the rural plain areas (Figures 1 & 2). The terrain in hilly areas is difficult to simulate in a lab, hence was not attempted in this study.

**Study Sample**

The study incorporated the convenience sampling strategy and recruited 7 chronic adult stroke survivors and 7 age- and gender-matched typical adults.

Stroke survivors were recruited for the study if they fulfilled the following criteria:

- Able to walk independently without orthotics and with or without walking aids on the target surfaces (Functional ambulatory category 4 & 5);
- Utilising walking as the major mode of ambulation with functional ROM and muscle strength in the lower extremity;
- Without any other pathologies or comorbidities that might influence gait pattern, including sensory-perceptual problems that may impair safety as identified in clinical examination;
- Orthopaedic dysfunction, fractures, vascular complications in the lower limb, lower limb or abdominal surgeries, cognitive impairments that may affect the safety of the participants;
- Had the stroke more than two years previously (post-natural recovery phase of stroke) (Skilbeck et al, 1983);
- Spasticity of more than 1 on a modified Ashworth Scale in the lower extremity; and,
- Age above 18 years.

Since this is a preliminary exploratory study, the sample size for typical adults was limited to data saturation. Data saturation was considered as the number of clients recruited who showed unique characteristics. After that, participants were recruited in whom no unique characteristics were identified (Saunders et al, 2018). Typical participants without any condition that could potentially affect gait, including orthopaedic systemic illnesses and cardiopulmonary morbidities, were recruited to match the stroke survivors in age and gender. Thus, 7 typical adults and 7 chronic stroke survivors were recruited as per criteria.

The recruited participants were informed about the study and written informed consent was obtained.

**Equipment and Study Protocol**

The study was performed in the gait laboratory of the institution in the simulated setting described earlier.

Two logistics 720 HD web cameras mounted on tripods (Neilsen et al, 2008; Patricoski et al, 2009) were connected to two laptops (32 bit Toshiba). Camera 1 was placed at the end of the walking area and 55cm above the floor so as to cover anterior and posterior views (Baker, 2006). Camera 2 was placed at a distance of 3 m lateral to the mid-portion of the walking area and 55cm above the floor to cover the lateral view (Figure 1).

**Figure 1: Illustration of Study Platform (even surface) and Technical Arrangements**

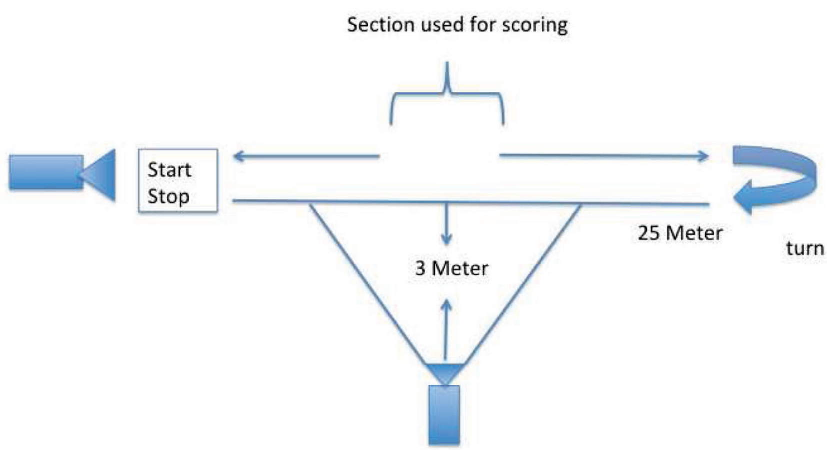
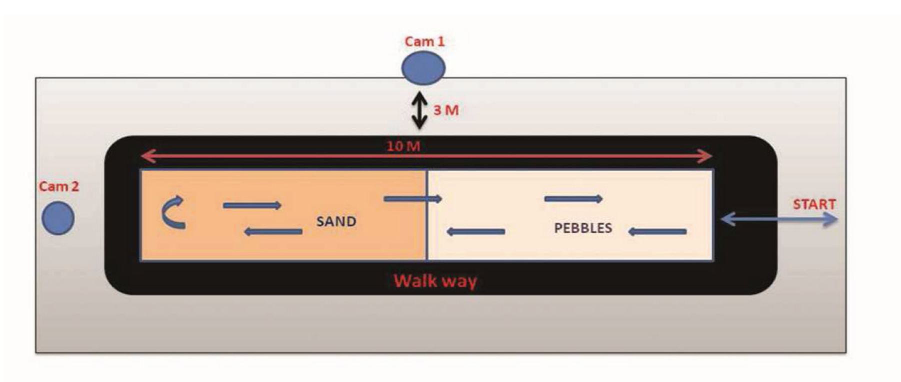



**Figure 2: Illustration of Study Platform (uneven surface) and Technical Arrangements**



To ensure the technical aspects of recording and adjustments, both laptops were operated by separate technicians. Greatest visualisation of the lower limb joints was ensured by fixing the optical axis of the camera in relation to the knee joint (Neilsen et al, 2008). The gait was captured at a frame rate of 30 fps (frames per second) and with a frame width of 1280×720 pixels.

### Participant Preparation

Relevant bony landmarks were exposed and marked with fluorescent colour tape markers of 25mm (Neilsen et al, 2008). The bony landmarks are given in Table 1(Mathew J et al, 2017).

**Table 1: List of Bony Landmarks identified**

| **List of Bony Landmarks identified** | |
|---|---|
| **Segment** | **Bony prominence** |
| Foot | -head of 1st metatarsal (dorsal)<br>-head of 3rd metatarsal (dorsal<br>-head of 5th metatarsal (lateral) |
| Ankle | -medial and lateral malleolus<br>-calcaneal tuberosity<br>-achilles tendon<br>-lower 1/3rd of tibia (anterior) |
| Knee | -lateral condyle of femur<br>-midpoint of patella |
| Hip and Pelvis | -greater trochanter<br>-anterior superior iliac spine<br>-posterior superior iliac spine<br>-iliac tubercle |
| Upper limbs | -radial and ulnar styloid process<br>-medial and lateral condyles of humerus<br>- acromion process |

### Video Recording

Video recording was completed in two phases.

In Phase 1, stroke survivors were allowed to become accustomed to the walkway. Following this, they were instructed to walk barefoot for two laps at a self-selected speed on the walking areas (even, sand and pebbled platforms respectively). For safety, a physiotherapist accompanied the participant without making direct contact. Gait belts were secured as per protocol to allow for the therapist to stabilise the client if needed. Recording on both cameras was done simultaneously.

In phase 2, the same procedure was repeated with age- and gender-matched typical adults.

### Video Analysis

Videos of typical participants were imported to Kinovea 0.8.15 version for analysis to draw normative values of range of motion (ROM) at the ankle and subtalar joints. Using different tools, the required points of the walking surfaces were marked on the software for better understanding (starting point, mid-portion, etc.). The initial and final 3 to 4 cycles of gait were not considered for analysis in order to control for initiation and fatigue. Thus, only the cycles covered in the middle 6m (3 to 4 cycles) were analysed. Joint kinematics was measured and recorded using different tools available in the software. Joint angles at the same event were taken from at least 3 consecutive cycles to increase the accuracy in measurement. Similarly, videos of stroke survivors were also analysed.

### Data Analysis

Due to the small sample size and the outliers, non-parametric tests were computed. Mann- Whitney U test was used for comparison. Descriptive statistics were computed where comparison was not possible.

### Ethics Approval

Approval from the institutional Ethical Committee of the affiliated Medical College was obtained (Reg No. 09_T046_95969).

# RESULTS

The demographic characteristics of participants are depicted in Table 2.

**Table 2: Demographic Profile of Participants (N=14)**

| | | Typical Adult | Person with Stroke |
|---|---|---|---|
| **Gender** | Male | 3 | 3 |
| | Female | 4 | 4 |
| **Side of stroke** | Right | [redacted] | 3 |
| | Left | [redacted] | 4 |
| **Range of motion of lower limb joints** | | Full | Functional for ambulation [8]. |

There was consistency of ROM among typical participants in ankle and subtalar range of motion during all phases of stance. The values on various surfaces are shown in Table 3.

**Table 3: Kinematic Profile of Typical Adults during Stance Phase of Gait on Different Surfaces**

| Events | Range of Motion(degrees) -Mean | | | | | |
|---|---|---|---|---|---|---|
| | Ankle Joint | | | Subtalar Joint | | |
| | Pebbles | Sand | Firm | Pebbles | Sand | Firm |
| *IC* | 8.3°-10.3 PF | 13.3° – 13.7DF | 1.7-3.1° PF | 12.3° – 14.6Ev | 11° -12.7Ev | 9.4-10.7°Ev |
| *LR* | 12° - 13.3PF | 11.3° – 12.6PF | 7.2-9.3° PF | 22.7° - 24Ev | 12.3° – 11.7Ev | 9.3-10.6°Ev |
| *MS* | 8.6° - 9.7DF | 5.3° – 6.7DF | 4.3-5.4° DF | 25.3° – 25.7Ev | 15.6° – 16.3Ev | 9.1-10.3°Ev |
| *TS* | 10° -13DF | 8.6° – 10DF | 8.0-9.1° DF | 12.7° – 13.6In | 9.6° – 10.3In | 8.6-9.3° In |
| *PS* | 7.6° - 8.3PF | 9° – 10PF | 9.4-11.3° PF | 13.6° – 15.7In | 12.3° – 13In | 8.0-9.2° In |

(IC- initial contact; LR - loading response; MS - mid stance; TS - terminal stand; PS - pre swing; PF - plantar flexion; DF - Dorsiflexion; Ev - eversion; In - inversion)

The kinematic profile of stroke survivors is given in Table 4.

**Table 4: Kinematic Profile of Stroke Survivors during Stance Phase of Gait on Different Surfaces**

| Events | Range of Motion(degrees) -Mean | | | | | |
|---|---|---|---|---|---|---|
| | Ankle Joint | | | Subtalar Joint | | |
| | Pebbles | Sand | Firm | Pebbles | Sand | Firm |
| *IC* | 5 PF-13.6 PF | 12 PF-15PF | 3.2-4.3 $^{o}$ PF | 16 Ev-18Ev | 11 Ev-12.7 Ev | 10.8 $^{o}$ eV-12.3 $^{o}$ eV |
| *LR* | 6 DF-9.3 PF | 10.6 PF-11.6 PF | 6.8-7.4 $^{o}$ PF | 10 Ev-21Ev | 11.7 Ev-12.6 Ev | 11.2 $^{o}$ Ev-12.6 $^{o}$ Ev |
| *MS* | 12.3 DF-7.6 PF | 8 PF-10.3 PF | 5.3-6.4 $^{o}$ DF | 21 Ev-23Ev | 16.3 Ev-16.8Ev | 15.9 $^{o}$ Ev-12.8 $^{o}$ Ev |
| *TS* | 4 DF-6.3 PF | 7.6 PF-12 PF | 8.1-9.0 $^{o}$ DF | 10 Ev-12Ev | 10.3 In-10.8 In | 8.6 $^{o}$ Ev-10.4 $^{o}$ Ev |
| *PS* | 3.3 PF-7.6 PF | 12 PF-14 PF | 9.6-11.0 $^{o}$ PF | 10 Ev-11 Ev | 12.6 In-13 In | 11.8 $^{o}$ Ev-12.8 $^{o}$ Ev |

(IC - initial contact; LR - loading response; MS - mid stance; TS - terminal stand; PS - pre swing; PF - plantar flexion; DF - Dorsiflexion; Ev - eversion; In - inversion)

During analysis, one client showed a large deviation in ROM from the other six. Hence this person's data was excluded from analysis.

During loading response (LR), a large difference in kinematics at ankle joint between the stroke survivors (6 $^{o}$ DF- 9.3 $^{o}$ PF) and typical adults (12 $^{o}$- 13.3PF) was noticed during gait on pebbles. During ambulation on sand, the kinematic profile of the stroke survivors was different from typical adults in all the events of stance at the ankle joint. Subtalar ROM was considerably reduced in stroke survivors on both sand and pebbles in comparison to typical adults.

## Ankle Joint

Due to the difference in the direction of movement (plantar flexion and dorsiflexion) between the two groups, only those phases of gait on similar surfaces (sand and pebble) where the movement was in the same direction for both groups were analysed using non-parametric test of comparison (Mann-Whitney U test). Results are summarised in Table 5.

**Table 5: Comparison of Plantar Flexion Range of Motion between Typical Adults and Persons with Stroke during Ambulation on Firm Surfaces**

| | Participants | Phases of Stance | | | | |
|---|---|---|---|---|---|---|
| | | **IC** | **LR** | **MS** | **TS** | **PS** |
| **ROM degrees (Mean ± SD)** | **Typical Adults** | 2.14±0.9 | 7.57±1.27 | 4.93 ±0.42 | 8.63 ±0.58 | 10.16 ±1.02 |
| | **Persons with Stroke** | 3.43 ±0.9 | 6.71 ±1.1 | 5.97 ±0.38 | 8.53 ±0.39 | 9.87 ±.0.55 |
| **Diff.(95% CI)** | | 1.29, [0.241, 2.338] | 0.86,[-0.523, 2.243] | 1.04, [0.573, 1.506] | 0.1,[-0.475, 0.675] | 0.29,[-0.664, 1.244] |
| **Z** | | -2.14 | -1.25 | -2.95 | -.13 | -0.6 |
| **P** | | 0.32 | 0.21 | 0.003 | 0.89 | 0.6 |

(ROM - Range of motion; IC - initial contact; LR - loading response; MS - mid stance; TS - terminal stand; PS - pre swing; PF - plantar flexion; DF – Dorsiflexion; Ev – eversion; In – inversion; SD - Standard deviation)

On firm surfaces, both groups (typical adults and stroke survivors) showed a similar direction of movement (plantar flexion). During initial contact (IC) and mid-stance (MS), plantar flexion was greater in stroke survivors than typical adults with greater differences noted in MS. But in loading response (LR), terminal stance (TS) and pre-swing (PS) plantar flexion was greater in typical adults than the stroke clients.

**Table 6: Differences in Plantar Flexion Range of Motion between Typical Adults and Persons with Stroke during Ambulation on Pebbled and Sand Surfaces**

| | Participants | Phases of Stance (Pebble) | | Phases of Stance (Sand) | |
|---|---|---|---|---|---|
| | | **IC** | **MS** | **IC** | **MS** |
| **ROM degrees (Mean ± SD)** | **Typical Adults** | 9.14±1.5 | 8.80±1.07 | 13.57±1.12 | 11.43±1.40 |
| | **Persons with Stroke** | 9.29±0.76 | 11.57±1.27 | 13.57±.98 | 10.71±0.76 |

| | | | | | |
|---|---|---|---|---|---|
| **Diff. (95% CI)** | | 0.15,[-1.234, 1.534] | 2.77,[1.402, 4.137] | 0,[-1.225, 1.225] | 0.72,[-0.591, 2.031] |
| **Z** | | -3.176 | -3.04 | -.137 | -1.008 |
| **P** | | 0.001 | 0.002 | 0.89 | 0.313 |

(ROM - Range of motion; IC - initial contact; MS - mid stance; SD - Standard deviation)

During ambulation on pebbled surfaces (Table 6), there was an increase in plantar flexion range of motion in stroke survivors in both IC and MS. Other phases of gait could not be compared as the direction of movement was opposite to each other in the two groups.

During ambulation on sand (Table 6), no statistically significant difference (p value=0.89) was noted between groups at IC but plantar flexion in typical adults was greater than the stroke group during LR.

## Subtalar Joint

**Table 7: Differences in Subtalar Joint Range of Motion between Typical Adults and Persons with Stroke during Ambulation on Firm Surfaces**

| | Participants | Phases of Stance | | | | |
|---|---|---|---|---|---|---|
| | | **IC** | **LR** | **MS** | **TS** | **PS** |
| **ROM degrees (Mean ± SD)** | **Typical Adults** | 10.23±.587 | 9.90±0.56 | 9.78±0.5 | 8.93.26 | 8.93±0.8 |
| | **Persons with Stroke** | 11.51±1.02 | 11.91±0.54 | 13.66±2.22 | 9.44±0.78 | 12.30±0.33 |
| **Diff. (95% CI)** | | 1.28,[0.310, 2.249]. | 2.01,[1.369, 2.650] | 3.88,[2.006, 5.754] | 0.51,[-0.167, 1.187] | 3.37,[2.657, 4.0827] |
| **Z** | | -2.18 | -3.13 | -3.13 | -1.54 | -3.14 |
| **P** | | 0.029 | 0.002 | 0.002 | 0.245 | 0.002 |

(ROM - Range of motion; IC - initial contact; LR - loading response; MS - mid stance, TS - terminal stand; PS - pre swing; PF - plantar flexion; DF - Dorsiflexion; Ev - eversion; In - inversion; SD - Standard deviation)

During ambulation on firm surfaces (Table 7), the subtalar joint showed a significantly greater range of motion in persons with stroke during all the phases of stance. The direction of movement was similar in both groups during all phases of gait; hence comparison was possible in all phases of gait. MS and PS phases showed maximum difference between groups in subtalar range of motion.

**Table 8: Differences in Subtalar Joint Range of Motion between Typical Adults and Persons with Stroke during Ambulation on Pebbled Surfaces**

| | Participants | Phases of Stance | | | | |
|---|---|---|---|---|---|---|
| | | **IC** | **LR** | **MS** | **TS** | **PS** |
| **ROM degrees (Mean ± SD)** | **Typical Adults** | 13.34±0.83 | 23.41±0.84 | 25.60±0.36 | 12.98±0.53 | 14.41±0.82 |
| | **Persons with Stroke** | 16.78±0.92 | 14.67±3.16 | 22.26±0.84 | 26.64±41.18 | 10.70±0.60 |
| **Diff. (95% CI)** | | 3.44,[2.419, 4.460] | 8.74,[6.047, 11.432] | 3.34,[2.587, 4.092] | 13.66,[-20.255, 47.575] | 3.71,[2.873, 4.546] |
| **Z** | | -3.134 | -3.130 | -3.137 | -2.049 | -3.130 |
| **P** | | 0.002 | 0.002 | 0.002 | 0.40 | 0.002 |

(ROM - Range of motion; IC - initial contact; LR - loading response; MS - mid stance; TS - terminal stand; PS - pre swing; PF - plantar flexion; DF - Dorsiflexion; Ev - eversion; In - inversion; SD - Standard deviation)

The direction of the movement of the subtalar joint during ambulation on the pebbled surface was similar between groups in all the phases of gait (Table 8). There was a large difference noted in the subtalar range of motion between groups in LR and TS.

**Table 9: Differences in Subtalar Joint Range of Motion between Typical Adults and Persons with Stroke during Ambulation on Sand**

| | ROM in Mean +/- SD | | | | |
|---|---|---|---|---|---|
| | **IC** | **LR** | **MS** | **TS** | **PS** |
| **Typical Adults** | 11.92±0.71 | 11.59±0.46 | 16.0±0.29 | 10.14±0.44 | 12.71±0.35 |

| | | | | | |
|---|---|---|---|---|---|
| **Persons with Stroke** | 12.0±0.66 | 16.54±0.20 | 10.57±0.24 | 12.61±0.35 | 10.87±4.35 |
| **Diff. (95% CI)** | 1.84,[-1.753, 5.433] | 4.95, [4.536, 5.363] | 5.43, [5.12, 5.74] | 2.47,[2.007, 2.933] | 1.84, [-1.753, 5.433] |
| **Z** | -1.38 | -3.14 | -3.14 | -3.14 | -1.42 |
| **P** | 0.701 | 0.002 | 0.002 | 0.002 | 0.155 |

(ROM - Range of motion; IC - initial contact; LR - loading response; MS - mid stance; TS - terminal stand; PS - pre swing; PF - plantar flexion; DF - Dorsiflexion; Ev - eversion; In -inversion; SD - Standard deviation)

During ambulation on sand, the subtalar range of motion was greater in the typical adult group than the stroke group during MS and PS. The subtalar range of motion was greater in the stroke sample than the typical adult sample at IC, LR and TS (Table 9).

## DISCUSSION

The researchers examined the differences in kinematic variables of ankle and subtalar joint during gait performance as the distal joints are crucial in gait stability. This study was conceived as a large observational study. However, the appearance of large potentially risky deviations in all participants compelled the curtailment of the study for ethical reasons. Hence this is presented as a preliminary explorative study. No research-related injury was reported during the study.

This study demonstrates that stroke survivors show vast deviations from typical adults in distal joint ROM. These results are consistent with existing literature that stroke survivors have limited ROM in primary joints, and compensatory movements may increase ROM in secondary joints. Reduced or altered ROM at the primary joints can be explained on the basis of excessive overactivity of ankle plantar flexors (Cappozzo et al, 2005; Yavuzer, 2006; Tranberg, 2010; Bensmail et al, 2013; Kim et al, 2016).

Typical adults show bilaterally symmetrical kinematic characteristics. Stroke survivors show similar ROM to typical adults on the unaffected side. The compensatory mechanisms seen in the affected side during the gait are a reversal of dorsiflexion and plantar flexion. This finding was unexpected and can be explained partially by the patterns adopted by clients. The primary intention of gait evaluation and analysis is to provide early intervention to improve the performance of clients. This study suggests that gait evaluation on uneven surfaces normally negotiated by the client must form a part of routine evaluation. Increased plantar flexion during swing resulting in foot drag is routinely considered during rehabilitation. Stance phase abnormalities are less often considered. Hence this paper focused on stance phase alterations only.

During ambulation on pebbled surfaces, plantar flexion was greater in stroke clients than in typical adults during initial contact and mid-stance. The reasons may be the greater reliance on gravity and inadequate co-contraction of the ankle musculature. This is a potential cause of ankle instability and recurrent minor trauma (Paolucci et al, 2008).

During ambulation on sand, IC and LR showed a similar direction of movement, with no significant difference between groups. The values are similar for both groups in this cohort. This could be due to the small size of the sample and the inclusion criteria adopted. Post hoc power analysis revealed a power of 0.4. This is a limitation of this study and further studies must consider this aspect. The confidence interval in many cases was wide which indicates that gait characteristics in stroke survivors are not similar, which can also be attributed to the small sample size. The direction of movement itself being altered in stroke survivors at the ankle joint is another notable finding. Due to this, factor comparisons were not made in ankle ROM during ambulation on sand and pebbles in various phases of gait. These factors further underpin the importance of outdoor gait evaluation as a potential tool for fall risk.

### Limitations

It is not possible to extract a definitive conclusion due to the smaller sample size. Hence this study is an initial exploratory study in this field. Further studies with a larger sample size are recommended.

## CONCLUSION

This is an exploratory study of seven individuals and no definitive conclusions can be drawn. However, the findings of this study are important as the deviations were remarkable and identify major fall risk, thereby having an impact on the quality of life of stroke survivors. Analysis of gait on uneven surface ambulation must be taken up as a large-scale study, given the burden of stroke survivors in India. The impact of gait deviations on joint kinetics is a future direction that will inform rehabilitation professionals on strategies to prevent joint loading leading to dysfunction. Early intervention strategies to improve joint kinematics on different surfaces can potentially reduce the risk of falls, making the client safe to ambulate on uneven terrains.

Routine assessment of stroke survivors concentrates mainly on indoor ambulation and function. When they return to the community, their activities and participation are often restricted. One factor may be difficulty in mobility. Mobility correlates highly with quality of life. The results of this study imply that gait deviations during ambulation on uneven surfaces are significant and must form a routine part of the assessment of stroke survivors. Meaningful strategies to adopt safe ambulation methods can be developed only with proper evaluation methods. This study shows a wide variation in ankle and foot strategies adopted by stroke survivors. This further underscores the importance of doing uneven level gait analysis. Since this is a clinical study without the use of instrumented gait analysis, further analysis using instrumentation is warranted in future research in order to develop a clinical assessment tool for evaluation of gait on outdoor surfaces.

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