The Immediate Impact of Hemodialysis on Gait Metrics

Relu Cernes MD[1,3], Oded Hershkovich MD MHA[2,3], Tatyana Tsehovsky MA[1], Neora Israeli[4], Mohr Wenger Michelson MSc[4], Yael Yankelevsky PhD[4], Omer Achrack MSc[4], Amit Gur MSc[4], Paola Ruiloba BA[4], Inbal Amedi[4], Leonid Feldman MD[1,3], and Raphael Lotan MD MHA[2,3]

[1]Department of Nephrology and Hypertension, Wolfson Medical Center, Holon, Israel
[2]Department of Orthopedic Surgery, Wolfson Medical Center, Holon, Israel
[3]Gray Faculty of Medical and Health Sciences, Tel Aviv University, Tel Aviv, Israel
[4]Intel Israel Ltd., Jerusalem, Israel

ABSTRACT

Background: Gait disturbances are common in patients undergoing hemodialysis and are associated with increased fall risk, mobility decline, and adverse health outcomes. Prior research suggests that hemodialysis may impact gait parameters such as speed, stride length, and variability; however, findings are inconsistent.

Objectives: To evaluate acute changes in gait metrics before and after hemodialysis using an artificial intelligence (AI) based video gait analysis system.

Methods: We initially enrolled 38 hemodialysis patients, two were excluded due to clothing interference with video analysis (27.8% female, 72.2% male). AI-driven gait analysis was performed immediately before and after dialysis. The system extracted spatiotemporal gait and joint range of motion. Statistical analyses included the Shapiro-Wilk test for normality, Wilcoxon signed-rank tests for non-normally distributed data, and paired *t*-tests for normally distributed data ($P < 0.05$).

Results: Gait speed (0.59 m/sec pre-dialysis) remained unchanged post-dialysis ($P = 0.876$), as did cycle length and time. However, step length significantly decreased post-dialysis ($P = 0.001$), suggesting a more conservative gait pattern. Knee flexion and extension increased slightly but did not reach statistical significance.

Conclusions: Dialysis does not acutely affect overall gait speed but significantly reduces stride length. Post-dialysis fatigue or hemodynamic shifts may alter walking patterns, highlighting the need for fall prevention strategies and physical rehabilitation interventions in dialysis care. AI-based gait analysis may provide a practical tool for monitoring mobility changes in hemodialysis patients.

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Gait disturbances are highly prevalent in patients undergoing hemodialysis and reflect broader impairments in physical function [1,2]. Individuals with end-stage kidney disease (ESKD) receiving hemodialysis demonstrate markedly reduced mobility, higher rates of assistive device use, and fall rates approximately two to three times higher than age-matched adults without chronic kidney disease (CKD) [3]. Mobility limitations in hemodialysis patients arise from sarcopenia, neuropathy, balance impairment, and hemodynamic instability related to fluid removal and uremia [4]. Falls and functional dependence contribute to hospitalization, fractures, diminished independence, and mortality; therefore, gait impairment is a key clinical concern in dialysis care [5,6].

Gait speed has emerged as an important marker of health status in CKD and is often referred to as the *sixth vital sign* [6]. Hemodialysis patients commonly walk at velocities below 0.8 m/s, a threshold associated with frailty and adverse outcomes [6]. Moorthi et al. [7] found that incident dialysis patients walked at a median of 0.78 m/s, with over half experiencing further decline within 2 years. Low gait speed is predictive of hospitalization, cognitive decline, cardiovascular events, and mortality. Beyond reduced velocity, hemodialysis patients often demonstrate shorter stride length, prolonged double-support phase, and increased gait variability [8,9]. These abnormalities reflect underlying deficits in balance and motor control and have been linked to increased fall risk [8]. Dialysis may acutely influence gait. Some studies have reported improved gait performance immediately post-treatment due to fluid removal and reduced edema, while others have shown worsening gait parameters attributed to fatigue, orthostatic symptoms, or blood pressure fluctuations [10,11]. Variability across studies may reflect differences in patient populations, co-morbidities, or gait testing protocols.

Understanding acute changes in gait following hemodialysis has clinical value because mobility fluctuations during the hours after treatment may increase fall risk and impair daily function [3]. Despite growing interest in gait

Table 1. Baseline demographic, clinical, and laboratory characteristics of study participants.

Characteristic	Overall
Participants, n	36
Age in years, mean ± SD	72 ± 11.1
Female sex, n (%)	10 (27.8%)
Male sex, n (%)	26 (71.2%)
Dialysis vintage in months, median [IQR]	31 [11–64]
Height in meters (mean ± SD)	1.68 ± 0.09
Pre-dialysis weight in kg (mean ± SD)	71.8 ± 16.8
Body mass index, kg/m², mean ± SD	25.4 ± 5.5
Kt/V, mean ± SD	1.43 ± 0.19
Hemoglobin, g/dl, mean ± SD	11.1 ± 1.6
Albumin, g/L, mean ± SD	39.7 ± 4.3
Creatinine, mg/dl, mean ± SD	4.1 ± 0.6
Urea, mg/dl, mean ± SD	108 ± 30
Sodium, mmol/L, mean ± SD	138.0 ± 3.5
Potassium, mmol/L, mean ± SD	4.9 ± 0.8
Calcium, mg/dl (mean ± SD)	9.0 ± 0.6
Phosphate, mg/dl, mean ± SD	5.0 ± 1.4
PTH, pg/ml, median [IQR]	245 [128–438]
CRP, mg/dl, median [IQR]	0.9 [0.2–2.5]
Diabetes mellitus, n (%)	18 (50%)
Hypertension, n (%)	31 (86%)
Ischemic heart disease, n (%)	10 (28%)
Congestive heart failure, n (%)	7 (19%)
Peripheral vascular disease, n (%)	4 (11%)
Prior stroke, n (%)	3 (8%)
Current smoker, n (%)	9 (25%)

abnormalities in dialysis patients, important knowledge gaps remain. Most studies rely solely on gait speed and lack detailed assessments of spatiotemporal gait parameters that reflect balance, coordination, and neuromuscular control [12]. Few investigations have examined quantitative gait metrics in relation to fall risk in CKD. Advanced gait assessment technologies, including sensor-based and markerless video systems, may improve detection of gait abnormalities and allow longitudinal monitoring in dialysis settings [13]. Applying artificial intelligence (AI) algorithms offers a promising, scalable approach to quantifying subtle gait changes during routine care.

In this study, we used an AI-based video gait analysis system to evaluate gait immediately before and after hemodialysis. We hypothesized that hemodialysis would acutely alter selected gait parameters and that detectable changes in stride length, cycle characteristics, or joint motion would reflect treatment-related physiological effects.

PATIENTS AND METHODS

This prospective observational study was conducted at a single hemodialysis center between September 2022 and April 2023. Eligible participants were adult patients (≥ 18 years) receiving maintenance hemodialysis three times weekly. Inclusion criteria required the ability to ambulate independently without a walking aid and willingness to provide written informed consent. Patients were excluded if they used walking aids that could interfere with gait measurement, had neurological conditions affecting gait (such as sequelae of stroke or Parkinson disease), were unable to understand the study procedures, or wore clothing that obstructed video analysis.

In total, 38 agreed to participate in the study and underwent gait recording immediately before and after a routine hemodialysis treatment. Two recordings were excluded due to incomplete visualization of lower limbs, yielding 36 paired assessments for analysis. In each session, patients walked along a standardized indoor walkway under identical lighting, flooring, and camera positioning. Video footage was acquired using a single stationary camera positioned at hip height and aligned perpendicular to the walking path to optimize limb visibility.

Gait recordings were analyzed using Intel IDI's machine learning-based, markerless pose-estimation system. The algorithm identifies skeletal key points from 2D video frames and converts pixel coordinates into metric units using subject height and camera calibration parameters. Real-time gait cycle detection enables extraction of spatiotemporal variables and joint range-of-motion parameters, including cycle length and duration, step length, foot clearance, stance and swing phases, and lower-limb angular excursions.

A standardized preprocessing workflow was implemented before statistical evaluation. Frames corresponding to turning motions were automatically excluded using a validated turn-recognition subroutine. Individual gait repetitions were then segmented and analyzed separately. Peak-based values (maximum or minimum) were extracted for each segment and aggregated using mean, standard deviation, and median values to reduce the influence of random fluctuations. Gait cycles deemed physiologic outliers were excluded to enhance reliability.

Demographic, anthropometric, dialysis, and laboratory variables were collected from electronic medical records. Patients served as their own controls, and paired before/after comparisons were performed. Continuous variables were assessed for normality using the Shapiro–Wilk test. Normally distributed parameters were compared using

Table 2. Paired pre- and post-hemodialysis gait changes in lower limb, upper limb, and trunk motion

	Mean difference	Shapiro *P*-Value	Shapiro statistic	Wilcoxon *P*-value	*P*-value
Cycle length (m)	0.06	0.408	0.969	0.880	0.985
Cycle time (mins)	0.04	0.148	0.955	0.315	0.442
Gait speed (m/sec)	0.003	0.092	0.948	0.858	0.876
Step length (cm)	-5.50	0.0004	0.865	0.0007	0.001
Foot clearance (cm)	-0.14	0.005	0.905	0.727	0.803
Pre- and post-hemodialysis change in lower limb joint and trunk motion while walking					
aAnkle dorsiflexion (deg)	-0.53	0.66	0.98	0.51	0.65
Ankle plantarflexion deg)	-1.68	0.01	0.92	0.12	0.16
Hip extension (deg)	-1.42	0.68	0.98	0.29	0.21
Hip flexion (deg)	0.68	0.02	0.92	0.15	0.48
Knee extension (deg)	2.83	0.48	0.97	0.07	0.06
Knee flexion (deg)	2.83	0.48	0.97	0.07	0.06
Trunk flexion (deg)	0.42	0.66	0.98	0.51	0.65
Pre- and post-hemodialysis change in upper limb joint motion while walking					
Elbow extension (deg)	-2.35	0.02	0.91	0.27	0.41
Elbow flexion (deg)	-2.35	0.02	0.91	0.27	0.41
Shoulder extension (deg)	1.28	0.07	0.93	0.45	0.33
Shoulder flexion (deg)	1.47	0.46	0.97	0.34	0.41

Figure 1. An AI-based skeleton representation of patient gait demonstrating automatic extraction of joint trajectories and gait cycles from video

The algorithm identifies key points and computes spatiotemporal gait parameters from 2D video input.

paired *t*-tests, whereas non-normally distributed parameters were analyzed using Wilcoxon signed-rank tests. Statistical significance was defined as $P < 0.05$. All analyses were performed using Python-based statistical packages.

The study protocol was reviewed and approved by the institutional research ethics committee and conducted according to the principles of the Declaration of Helsinki. All participants provided written informed consent before enrollment. AI-assisted technology was used only for gait parameter extraction. Clinical interpretation and analysis were performed by the investigators. The authors reviewed the output of automated processing pipelines to verify accuracy and validity.

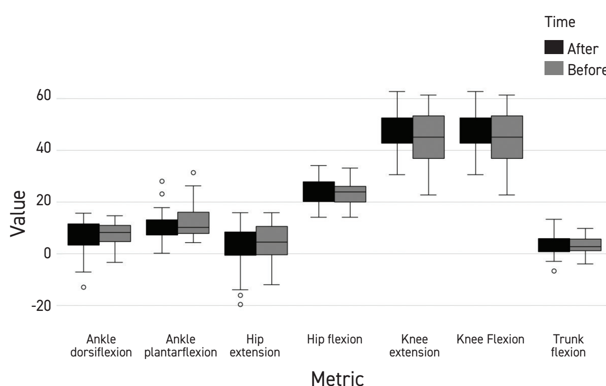
RESULTS

In total, 38 videos of dialysis patients walking, which captured gait before and after dialysis, were recorded [Figure 1]. Videos from two patients were excluded due to inadequate visualization of the lower limbs, yielding 36 complete paired pre- and post-dialysis assessments (27.8% female). Baseline demographic, hemodynamic, and laboratory characteristics are shown in Table 1. Mean age was 72 ± 11 years, dialysis vintage 31 months [IQR 11–64], and mean pre-dialysis weight was 71.8 ± 16.8 kg. Hypertension (86%) and diabetes (50%) were the most prevalent co-morbidities.

All participants ambulated independently. Mean pre-dialysis gait speed was 0.59 m/s. Table 2 summarizes paired within-participant comparisons. No significant differences were observed in global rhythm or temporal gait parameters after dialysis. Cycle length ($P = 0.985$), cycle time ($P = 0.442$), and gait speed ($P = 0.876$) remained essentially unchanged pre- vs post-treatment. Foot-clearance reductions did not reach statistical significance ($P = 0.803$).

Figure 2. Pre- and post-hemodialysis change in gait metrics

Box-plots illustrate paired comparisons of gait rhythm and spatial parameters before and immediately after hemodialysis. Step length significantly decreased after dialysis (*P* = 0.001), while gait speed, cycle length, and cycle time showed no significant change. Foot clearance changes did not reach statistical significance.



By contrast, step length decreased significantly post-dialysis (mean -5.5 cm; paired *t*-test *P* = 0.001; Wilcoxon *P* = 0.0007). This was the only spatial gait parameter demonstrating a robust treatment effect and suggests adoption of a more conservative gait pattern immediately after hemodialysis.

Joint kinematic changes were small. Ankle dorsiflexion and plantarflexion decreased slightly (*P* = 0.65 and *P* = 0.16). Hip motion varied minimally (*P* > 0.20). Knee flexion and extension increased by 2.83, approaching significance (*P* = 0.06 for both statistical tests). Trunk flexion changes were negligible (*P* = 0.65). Upper-limb motion demonstrated minor, non-significant directional shifts (*P* = 0.33–0.45), indicating relative preservation of arm swing.

Considerable inter-individual variability was noted across gait responses, with some patients showing marked improvements or declines despite stable group means [Figure 2]. This finding suggests heterogeneous physiological responses to dialysis and highlights the potential utility of repeated individualized gait monitoring.

In summary, hemodialysis did not acutely affect global gait rhythm or speed but rather produced a statistically significant reduction in step length with borderline increases in knee motion. These findings indicate preserved locomotor timing but reduced spatial efficiency and potentially compensatory strategies to maintain stability in the immediate post-dialysis period. Given the elevated fall risk in hemodialysis patients, this situation may represent a clinically vulnerable window.

DISCUSSION

In this study, we investigated the immediate impact of hemodialysis on gait metrics using an AI-based video gait analysis system. Our main finding was that step length significantly decreased following dialysis, while gait speed, cycle length, and cycle time did not change. These results suggest that although global gait rhythm remains stable, the dialysis session may acutely alter spatial gait parameters and prompt patients to adopt a more conservative walking strategy. This observation aligns with previous studies, which reported reduced gait performance after dialysis [9,11], although others found improved mobility with fluid removal [10,11], indicating that gait responses to dialysis may vary among patients.

The reduction in step length may reflect post-dialysis fatigue, orthostatic symptoms, or transient hemodynamic instability. Wolfgram and colleagues [11] reported an average post-dialysis gait speed decline of 0.06 m/s, which supports the hypothesis that physiological stress during dialysis can impair gait. In our study, the preservation of gait speed despite shorter step length suggests compensatory adaptations (e.g., maintaining cadence) to preserve forward progression. Conversely, parameters influenced by chronic CKD sequelae such as muscle weakness, neuropathy, and balance deficits may show limited acute responsiveness to a single dialysis session [14]. Persistent abnormalities before and after treatment likely reflect chronic neuromuscular impairments rather than fluid-related fluctuations [15].

The practical implications of these findings are clinically relevant. Even subtle worsening of gait parameters after dialysis could increase fall risk. Dialysis patients already have a higher incidence of falls than age-matched controls [2,3,16], and acute instability following treatment may represent a particularly vulnerable period. Fatigue and intradialytic hypotension have been linked to impaired physical function and falls [17,18]. Fall-prevention strategies such as advising patients to rest briefly after dialysis, stand slowly, and avoid rushing out of the unit may mitigate risk. Rehabilitation interventions including supervised exercise, balance training, or intradialytic training programs have demonstrated improvements in gait performance in dialysis populations [14]. Integrating such strategies could enhance safety and preserve functional independence.

A notable highlight of this study is the application of a markerless AI-based video analysis system. This technology enables rapid, automated extraction of gait parameters in a real-world clinical setting and overcomes practical and logistical barriers associated with traditional gait

laboratories. Our results suggest that routine, repeated gait assessments in dialysis units may be feasible and could help clinicians track functional trajectories over time. Such monitoring may identify patients at heightened risk of mobility decline, guide referral to rehabilitation services, or prompt review of dialysis prescriptions in cases where excessive ultrafiltration or hemodynamic instability contributes to adverse gait changes [19,20].

This study has several limitations that warrant consideration. The cohort was relatively small and came from a single center, thus limiting generalizability. Participants were predominantly older adults receiving in-center hemodialysis, and findings may not apply to home dialysis modalities or younger patients. We assessed gait immediately before and after a single session. The temporal profile of recovery after dialysis remains unknown. Additional assessments several hours post-dialysis or the following day would clarify the duration of functional impairment. The evaluation walkway was short, and although validated, may not fully capture steady-state gait or endurance-related parameters. Moreover, potential confounders such as blood pressure at the time of gait measurement were not formally recorded, and mild hypotension could have independently affected performance [6,7].

CONCLUSIONS

In this study, we demonstrated that while global gait rhythm is maintained, step length acutely decreases after hemodialysis, reflecting subtle impairments in gait stability and efficiency. These findings highlight the need for fall-prevention strategies and functional mobility assessment in routine dialysis care. AI-driven markerless gait analysis offers a practical method to monitor mobility in real-world settings and may enable early detection of functional decline. Future studies should evaluate long-term gait trajectories after dialysis, explore mechanisms underlying individual variability in gait response, and assess whether incorporating gait monitoring into dialysis care improves patient safety and outcomes.

Correspondence

Dr. R. Cernes
Dept. of Nephrology and Hypertension, Wolfson Medical Center, Holon 5822012, Israel
Phone: (972-3) 502-8289
Email: relucernes@gmail.com

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