Journal of Orthopaedics 49 (2024) 172–179

Contents lists available at ScienceDirect

Journal of Orthopaedics

journal homepage: www.elsevier.com/locate/jor

Gait variability and biomechanical distinctions in knee osteoarthritis: Insights from a 3D analysis in an adult elderly cohort

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ARTICLE INFO

Keywords:
Gait analysis
Knee osteoarthritis
Temporospatial parameters
Gait profile score
Motion analysis profile

ABSTRACT

Background: This study employs 3D gait analysis to investigate normal gait patterns in individuals afflicted with knee Osteoarthritis (OA). Focusing on the adult osteoarthritic population, the research aims to establish reference values for joint angles, temporospatial parameters, Gait Profile Score (GPS), and Movement Analysis Profile (MAP) collected concurrently along a standardized walking path. Furthermore, the study delves into potential variations linked to gender and OA severity, comparing gait parameters between male and female participants and among individuals with grade 3 and grade 4 OA.
Method: The study involved 34 adults with a mean age of 68.6 ± 5.75 years, all experiencing OA knees and awaiting Total Knee Arthroplasty (TKA). Utilizing Qualisys Motion capture system, 3D gait analysis was conducted. Data were processed through Visual 3D C-Motion Software.
Results: Gait analysis revealed noteworthy differences between genders for various parameters, including stance time, GPS, MAP of the hip, and joint angle for the sagittal plane (ankle), coronal plane (knee), and transverse plane (hip and knee). Moreover, significant differences were observed between grade 3 and grade 4 OA knees in MAP and for the transverse plane joint angle (ankle).
Conclusion: This gait analysis study sheds light on distinctive gait patterns in the adult osteoarthritic population. The identified variations in temporospatial parameters, joint angles, GPS, and MAP provide valuable reference values for individuals suffering from knee OA. The observed differences between genders and across different OA severity grades emphasize the need for personalized approaches in managing knee OA and planning interventions like TKA.

1. Introduction

A pain-free, erect, bipedal gait is essential for conducting routine daily activities. In elderly individuals, knee pain and deformities significantly impede knee function, consequently impacting overall gait. Gait analysis serves as a non-invasive, convenient, and reproducible method to examine full-body kinematics, encompassing positioning variables of the pelvis, hip, knee, and ankle in the coronal, sagittal, and rotational planes.[1–4] Gait analysis is an excellent tool for the diagnosis of musculoskeletal disorders,[5,6] surgical outcome evaluation, gait training process, physiotherapy interventions, and evaluating the effectiveness of different walking aids.[5,7] Gait, as an indicator, can be employed to evaluate the quality of life,[8] health status,[9] physical function,[10] and predictor of falls or indicator of fear.[11] The variation in walking patterns connected to knee OA differs based on gender as well as the severity of OA.[12] Individuals with knee OA demonstrate an extended gait cycle, decreased cadence, reduced step length, and slower walking speed when compared to their healthy counterparts.[13] Individuals with OA employ compensatory mechanisms to diminish the knee extensor moment, thereby reducing the overall loading on the knee joint.[14] As the severity of OA increases, there is a tendency for reduced abduction of the ankle joints during stance, aiming to prevent knee adduction.[15] However, current research predominantly concentrates on a limited number of gait parameters, emphasizing peak values, while values at different stages of the gait cycle remain unexplored.

The GPS is a raw score representing the overall severity of a

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https://doi.org/10.1016/j.jor.2023.12.011
Received 12 December 2023; Accepted 17 December 2023
Available online 23 December 2023
0972-978X/

condition affecting walking, calculated as the RMS difference in degrees between an individual's gait data and the average data from those without gait pathology, while the MAP is derived from gait variable scores, offering insights into specific kinematic variables contributing to the overall GPS.[16]

The most frequently cited benchmark for gait performance is gait speed. Among adults between the ages of 70 and 79, the average gait speed typically falls within the range of approximately 90–130 cm/s.[6,17,18] Normative studies[17,18] tend to yield higher gait parameter values compared to population-based studies,[5,6] likely because normative reference studies characterize the gait of healthy populations, while population-based studies predominantly focus on describing gait within pathological conditions.

To date, existing research has primarily focused on referencing or establishing normative data for singular parameter groups, such as spatiotemporal or joint kinematics. However, a compilation of normative data for the elderly population afflicted with knee OA is notably absent in the literature. Consequently, this study aims to establish reference values for joint angles, temporospatial parameters, GPS, and MAP, concurrently collected along the same walking path in the adult osteoarthritic Indian population. Additionally, to address potential variations associated with gender and OA severity, the study seeks to compare gait parameters between male and female participants and among individuals with grade 3 and grade 4 OA. The acquisition of such data is anticipated to enhance the ability of orthopedic surgeons and physiotherapists to more precisely interpret gait dysfunction and devise interventions tailored to the specific needs of this demographic.

2. Methods

Data was extracted from a cohort of 34 (26 female and 8 male) patients diagnosed with knee OA, whose average age was 68.6 ± 5.75 years. The gait analysis, performed sequentially and without randomization, focused on patients with OA. The categorization of patients was based on the Kellgren-Lawrence radiographic OA classification, specifically identifying individuals as grade 3 (moderate OA) or grade 4 (severe OA).

2.1. Procedure

A total of 36 reflective markers (20 individual reflective markers and 4 cluster markers, each comprising 4 markers) with a diameter of 16 mm were affixed to anatomical bony landmarks using double-sided adhesive tape, following the CAST (6DOF) model[19] as shown in Fig. 1. This marker placement procedure was consistently conducted by the same investigator across all subjects. Each participant performed two walks along the walkway, with the initiation and termination of each walk occurring 0.5 m before and after the walkway to mitigate the acceleration effect. The data from both walks were subsequently amalgamated and presented as a unified dataset representing the participant's walking activity.

2.2. Instrumentation

Gait analysis was executed in a sophisticated gait laboratory equipped with 9 Qualisys Oqus camera systems (Qualisys AB, Sweden). Data

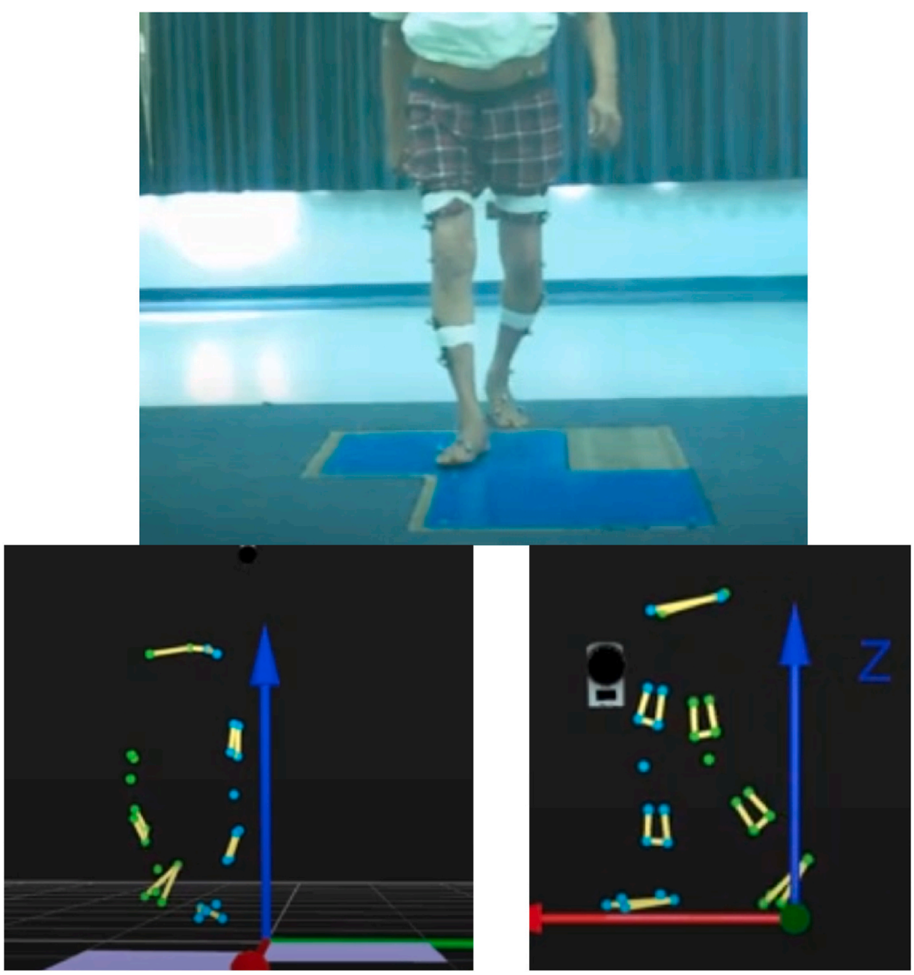

Fig. 1. Marker placement diagram.

acquisition and analysis were conducted using Qualisys Track Manager, a motion capture system, with a sampling frequency of 120 Hz. Data were meticulously processed employing Visual 3D C-Motion Software. The midpoint of various events within the gait cycle was documented in joint angle comparison (Barefoot) graphs, which were generated post-gait analysis and integrated temporospatial information, GPS, and MAP data.

2.3. Data collection

We gathered data encompassing 8 spatio-temporal parameters, as well as joint angles of the pelvis, hip, knee, and ankle in sagittal, coronal, and transverse planes at various gait phases. Additionally, GPS and 9 variables of MAP were collected, stratified by gender and grade 3 and grade 4 OA.

2.4. Statistical analysis

Statistical analysis was performed using IBM® SPSS® 20.0. To compare the two groups, Fisher's test and independent sample *t*-test were employed for categorical and continuous variables, respectively. Statistical significance was established at $p < 0.05$.

3. Results

In this study, demographic variables were initially subjected to statistical analysis to assess homogeneity. There was a significant difference between the genders in height and body mass index (BMI), but no such difference was noted in grade 3 and grade 4 OA knee. No significant difference was found between the genders for age and weight (Table 1).

3.1. Spatio-temporal

There was a lack of significant difference observed in spatio-temporal parameters between Severe OA and Moderate OA (Table 2). However, a significant disparity was noted in stance time, while no significant differences were observed in other spatio-temporal parameters between males and females (Table 2).

3.2. GPS and MAP

No significant disparity emerged between severe OA and moderate OA in GPS (Table 3). However, a significant difference was noted in the GPS between males and females (Table 3). In the Knee_FE MAP, there was a significant difference observed between severe OA and moderate OA, while no significant differences were found in other parameters (Table 4). Additionally, a significant difference was identified in the Hip_IE MAP between males and females, with no significant differences observed in other parameters (Table 4).

Table 1
Demographics of severe OA vs moderate OA and male vs female.

Parameters	Severity/Gender	Number	Mean	SD	p-value
Age	Severe OA	25	68.04	4.73	0.30
	Moderate OA	9	70.44	8.41	
Height	Severe OA	25	1.54	0.08	0.26
	Moderate OA	9	1.58	0.10	
Weight	Severe OA	25	72.25	12.88	0.28
	Moderate OA	9	66.99	10.18	
BMI	Severe OA	25	30.47	5.48	0.08
	Moderate OA	9	26.84	3.69	
Age	Male	8	71.50	7.31	0.12
	Female	26	67.81	5.24	
Height	Male	8	1.63	0.05	0.002[a]
	Female	26	1.53	0.08	
Weight	Male	8	64.03	9.62	0.07
	Female	26	72.96	12.42	
BMI	Male	8	23.99	2.83	0.0002[a]
	Female	26	31.20	4.66	

[a] Indicates significant difference.

Table 2
Spatio-temporal severe OA vs moderate OA and male vs female.

Parameters	Severity	Number	Mean	Standard Deviation	p-value
Speed (cm/s)	Severe OA	25	70.30	24.72	0.63
	Moderate OA	9	65.67	23.01	
Cadence (steps/min)	Severe OA	25	88.04	19.83	0.51
	Moderate OA	9	92.78	12.91	
Initial double limb support (s)	Severe OA	46	0.16	0.08	0.62
	Moderate OA	21	0.17	0.09	
Stance time (% gait cycle)	Severe OA	46	59.88	10.11	0.72
	Moderate OA	21	60.97	14.36	
Step time (s)	Severe OA	46	0.68	0.11	0.35
	Moderate OA	21	0.65	0.11	
Step length (m)	Severe OA	46	0.39	0.09	0.34
	Moderate OA	21	0.37	0.11	
Stride width (m)	Severe OA	25	0.13	0.04	0.11
	Moderate OA	9	0.16	0.04	
Stride length (m)	Severe OA	25	0.80	0.20	0.22
	Moderate OA	9	0.70	0.20	
Speed (cm/s)	Male	8	72.57	21.32	0.65
	Female	26	68.00	25.09	
Cadence (steps/min)	Male	8	91.25	9.59	0.73
	Female	26	88.69	20.23	
Initial double limb support (s)	Male	15	0.16	0.08	0.91
	Female	52	0.16	0.08	
Stance time (% gait cycle)	Male	15	54.22	22.26	0.02[a]
	Female	52	61.95	4.67	
Step time (s)	Male	15	0.66	0.08	0.79
	Female	52	0.67	0.12	
Step length (m)	Male	15	0.39	0.10	0.77
	Female	52	0.38	0.10	
Stride width (m)	Male	8	0.14	0.04	0.92
	Female	26	0.14	0.04	
Stride length (m)	Male	8	0.79	0.21	0.73
	Female	26	0.76	0.20	

[a] Indicates significant difference.

Table 3
Gait profile score severe OA vs moderate OA and male vs female.

Parameters	Gender	Number	Mean	SD	p-value
GPS	Severe OA	46	10.40	2.58	0.73
	Moderate OA	21	10.16	2.75	
Average gait	Severe OA	23	11.25	2.64	0.48
	Moderate OA	9	10.53	2.37	
GPS	Male	15	8.91	2.68	[a]0.02
	Female	52	10.73	2.48	
Average Gait	Male	7	9.50	2.81	0.07
	Female	25	11.48	2.35	

[a] Indicates significant difference.

3.3. Joint angle

There were significant differences observed in ankle coronal TS, ankle coronal ISW, ankle transverse IS, ankle transverse MS, ankle transverse TS, and ankle transverse ISW between Severe OA and Moderate OA, while no significant differences were found in other parameters (Table 5). Similarly, significant differences were identified in knee coronal TS, knee coronal ISW, knee coronal MSW, ankle sagittal MS, ankle sagittal TS, hip sagittal IS, hip transverse MS, hip transverse TS,

Table 4
Motion analysis profile severe OA vs moderate OA and male vs female.

Parameters	Gender	Number	Mean	SD	p-value
Pelvis_AP	Severe OA	25	5.04	2.78	0.62
	Moderate OA	9	4.48	3.14	
Hip_FE	Severe OA	46	10.38	6.41	0.46
	Moderate OA	21	9.24	4.06	
Knee_FE	Severe OA	46	11.86	5.02	0.001[a]
	Moderate OA	21	7.60	3.04	
Ankle_DP	Severe OA	46	10.10	2.91	0.59
	Moderate OA	21	9.73	1.95	
Pelvis_UD	Severe OA	25	5.74	2.31	0.51
	Moderate OA	9	6.36	2.43	
Hip_AdAb	Severe OA	46	8.70	3.49	0.72
	Moderate OA	21	8.36	3.44	
Pelvis_IE	Severe OA	25	7.22	1.85	0.84
	Moderate OA	9	7.38	2.48	
Hip_IE	Severe OA	46	14.45	7.24	0.07
	Moderate OA	21	18.30	9.17	
Foot_IE	Severe OA	46	7.75	4.71	0.25
	Moderate OA	21	9.16	4.51	
Pelvis_AP	Male	8	5.15	3.14	0.78
	Female	26	4.82	2.80	
Hip_FE	Male	15	8.31	3.77	0.19
	Female	52	10.52	6.17	
Knee_FE	Male	15	9.74	5.67	0.48
	Female	52	10.76	4.68	
Ankle_DP	Male	15	9.35	1.50	0.29
	Female	52	10.17	2.87	
Pelvis_UD	Male	8	5.68	2.76	0.75
	Female	26	5.98	2.22	
Hip_AdAb	Male	15	8.13	4.05	0.56
	Female	52	8.72	3.30	
Pelvis_IE	Male	8	7.74	2.81	0.45
	Female	26	7.11	1.72	
Hip_IE	Male	15	12.13	6.03	0.052[a]
	Female	52	16.68	8.29	
Foot_IE	Male	15	7.10	4.06	0.31
	Female	52	8.51	4.81	

AP: Anterior/Posterior, FE: Flexion/Extension, DP: Dorsi/Plantar, UD:Up/Down, AdAb: , abduction/adduction IE: Internal/External.
[a] Indicates significant difference.

Table 5
Joint angle severe OA vs moderate OA.

	Parameters	Severity	Mean	SD	P-value
Sagittal					
Pelvis	IS	Severe OA	13.70	5.66	0.25
		Moderate OA	12.08	4.52	
	MS	Severe OA	14.00	6.16	0.46
		Moderate OA	12.84	5.24	
	TS	Severe OA	13.15	5.85	0.25
		Moderate OA	11.48	4.66	
	ISW	Severe OA	13.13	5.85	0.24
		Moderate OA	11.40	4.69	
	MSW	Severe OA	13.97	5.74	0.32
		Moderate OA	12.48	5.38	
	TSW	Severe OA	13.61	5.75	0.38
		Moderate OA	12.34	4.88	
Hip	IS	Severe OA	26.65	11.07	0.53
		Moderate OA	24.87	9.69	
	MS	Severe OA	15.29	11.75	1.00
		Moderate OA	15.30	7.66	
	TS	Severe OA	5.53	10.37	0.93
		Moderate OA	5.74	7.03	
	ISW	Severe OA	13.15	11.50	0.80
		Moderate OA	13.87	7.88	
	MSW	Severe OA	32.13	11.45	0.89
		Moderate OA	31.76	8.75	
	TSW	Severe OA	32.08	11.14	0.56
		Moderate OA	30.43	9.50	
Knee	IS	Severe OA	15.58	9.62	0.63
		Moderate OA	14.48	5.77	
	MS	Severe OA	15.00	9.75	0.47
		Moderate OA	13.35	5.12	
	TS	Severe OA	24.05	11.30	0.81
		Moderate OA	23.38	9.35	
	ISW	Severe OA	29.75	13.53	0.96
		Moderate OA	29.92	9.24	
	MSW	Severe OA	46.45	17.03	0.10
		Moderate OA	53.18	9.46	
	TSW	Severe OA	12.72	8.91	0.62
		Moderate OA	11.69	4.99	
Ankle	IS	Severe OA	2.69	3.86	0.54
		Moderate OA	2.06	4.05	
	MS	Severe OA	11.59	5.74	0.43
		Moderate OA	10.40	5.41	
	TS	Severe OA	13.83	7.64	0.91
		Moderate OA	14.07	7.47	
	ISW	Severe OA	1.65	6.73	0.37
		Moderate OA	−0.07	8.43	
	MSW	Severe OA	10.46	4.56	0.42
		Moderate OA	9.45	5.12	
	TSW	Severe OA	3.84	4.63	0.41
		Moderate OA	2.78	5.50	
Coronal					
Pelvis	IS	Severe OA	0.09	3.56	0.34
		Moderate OA	−0.79	3.39	
	MS	Severe OA	−2.68	5.95	0.22
		Moderate OA	−4.54	5.05	
	TS	Severe OA	1.35	3.65	0.23
		Moderate OA	0.16	3.86	
	ISW	Severe OA	2.77	4.53	0.15
		Moderate OA	1.10	3.95	
	MSW	Severe OA	4.95	4.86	0.36
		Moderate OA	3.78	4.67	
	TSW	Severe OA	1.66	3.87	0.57
		Moderate OA	1.12	2.97	
Hip	IS	Severe OA	−0.08	6.07	0.95
		Moderate OA	0.03	6.06	
	MS	Severe OA	−4.19	8.22	0.51
		Moderate OA	−2.73	8.93	
	TS	Severe OA	0.26	6.94	0.93
		Moderate OA	0.12	5.50	
	ISW	Severe OA	0.08	7.01	0.37
		Moderate OA	2.54	15.40	
	MSW	Severe OA	1.16	7.11	0.95
		Moderate OA	1.05	6.33	
	TSW	Severe OA	0.36	6.22	0.38
		Moderate OA	1.78	5.63	

(*continued on next page*)

hip transverse ISW, hip transverse MSW, hip transverse TSW, knee transverse MS, knee transverse TS, and knee transverse TSW between males and females, with no significant differences noted in other parameters (Table 6).

4. Discussion

Our study established reference values for joint angles, temporospatial parameters, GPS, and MAP concurrently collected along the same walking path among the adult osteoarthritic Indian population. Our findings revealed significant differences in gait parameters between males and females, as well as among individuals with grade 3 and grade 4 OA. Despite the existing gap in normative data for the biomechanics of adult patients with knee osteoarthritis, our study addresses this limitation by specifically concentrating on joint angles, temporospatial parameters, GPS, and MAP in the context of adult knees affected by osteoarthritis.

4.1. Spatio-temporal parameters

Patients are instructed to walk on the walkway at a self-selected speed to attain their most natural walking pattern, as the gait pattern is influenced by an increase or decrease in gait speed.[20] The average gait speed defined as "self-selected", observed in our studied group was 72.57 ± 21.32 cm/s for males and 68 ± 25.09 cm/s for females. The average gait speed of our studied population was 69.07 ± 24.02 cm/s, which was lower than Hollman et al.[21] (110 ± 19 cm/s) and Oh-Park et al.[22] (106 cm/s) normative reference speed. The mean difference

Table 5 (*continued*)

	Parameters	Severity	Mean	SD	P-value
Knee	IS	Severe OA	4.11	7.34	0.12
		Moderate OA	0.90	8.39	
	MS	Severe OA	5.74	6.62	0.06
		Moderate OA	2.25	7.84	
	TS	Severe OA	2.96	6.79	0.17
		Moderate OA	0.32	8.27	
	ISW	Severe OA	−0.72	7.59	0.93
		Moderate OA	−0.94	11.04	
	MSW	Severe OA	3.22	6.99	0.35
		Moderate OA	1.30	9.33	
	TSW	Severe OA	3.38	6.44	0.15
		Moderate OA	0.68	8.22	
Ankle	IS	Severe OA	1.71	5.54	0.40
		Moderate OA	2.95	5.66	
	MS	Severe OA	−3.83	3.52	0.10
		Moderate OA	−2.18	4.26	
	TS	Severe OA	5.46	5.03	0.047[a]
		Moderate OA	8.37	6.27	
	ISW	Severe OA	5.93	6.13	0.045[a]
		Moderate OA	9.34	6.82	
	MSW	Severe OA	5.18	5.08	0.30
		Moderate OA	6.51	4.35	
	TSW	Severe OA	3.28	5.39	0.27
		Moderate OA	4.87	5.57	
Transverse					
Pelvis	IS	Severe OA	1.74	5.32	0.98
		Moderate OA	1.71	4.55	
	MS	Severe OA	3.39	5.11	0.88
		Moderate OA	3.60	5.80	
	TS	Severe OA	−1.61	5.01	0.87
		Moderate OA	−1.39	4.90	
	ISW	Severe OA	−2.31	5.10	0.80
		Moderate OA	−2.65	5.02	
	MSW	Severe OA	−2.86	5.63	0.89
		Moderate OA	−3.07	5.69	
	TSW	Severe OA	0.09	4.56	0.87
		Moderate OA	0.29	4.32	
Hip	IS	Severe OA	−10.36	9.81	0.74
		Moderate OA	−11.35	13.38	
	MS	Severe OA	−13.56	10.28	0.66
		Moderate OA	−14.92	14.28	
	TS	Severe OA	−9.84	13.09	0.91
		Moderate OA	−10.28	18.86	
	ISW	Severe OA	−11.13	9.95	0.88
		Moderate OA	−11.58	14.61	
	MSW	Severe OA	−9.80	10.86	0.82
		Moderate OA	−10.55	15.24	
	TSW	Severe OA	−10.08	12.19	0.38
		Moderate OA	−13.13	14.91	
Knee	IS	Severe OA	−1.86	10.79	0.36
		Moderate OA	−4.52	11.27	
	MS	Severe OA	0.42	10.93	0.46
		Moderate OA	−1.78	11.49	
	TS	Severe OA	−1.01	11.15	0.55
		Moderate OA	−2.81	12.26	
	ISW	Severe OA	−3.39	12.33	0.63
		Moderate OA	−4.92	11.71	
	MSW	Severe OA	−3.44	12.26	0.65
		Moderate OA	−4.91	12.20	
	TSW	Severe OA	−5.36	11.75	0.76
		Moderate OA	−6.30	12.15	
Ankle	IS	Severe OA	−14.91	8.06	0.01[a]
		Moderate OA	−20.13	6.64	
	MS	Severe OA	−13.17	10.47	0.01[a]
		Moderate OA	−19.78	6.75	
	TS	Severe OA	−12.98	9.89	0.01[a]
		Moderate OA	−19.39	6.96	
	ISW	Severe OA	−12.16	10.20	0.01[a]
		Moderate OA	−18.68	7.16	
	MSW	Severe OA	−19.15	9.72	0.054
		Moderate OA	−23.89	7.83	
	TSW	Severe OA	−15.57	9.24	0.14
		Moderate OA	−19.57	11.69	

IS: initial stance, MS: midstance, TS: terminal stance, ISW: initial swing, MSW: mid swing, TSW: terminal swing.

[a] Indicates significant difference.

Table 6
Joint angle male vs female.

	Parameters	Gender	Mean	SD	p-value
Sagittal					
Pelvis	IS	Male	12.30	5.83	0.47
		Female	13.45	5.23	
	MS	Male	12.60	6.25	0.44
		Female	13.94	5.79	
	TS	Male	11.96	5.91	0.60
		Female	12.82	5.45	
	ISW	Male	11.98	5.97	0.63
		Female	12.76	5.46	
	MSW	Male	12.74	6.26	0.56
		Female	13.72	5.49	
	TSW	Male	12.22	5.63	0.43
		Female	13.50	5.46	
Hip	IS	Male	25.70	9.08	0.87
		Female	26.21	11.09	
	MS	Male	14.33	7.22	0.69
		Female	15.57	11.41	
	TS	Male	5.53	6.23	0.98
		Female	5.62	10.18	
	ISW	Male	15.00	5.85	0.50
		Female	12.91	11.44	
	MSW	Male	30.00	7.94	0.41
		Female	32.59	11.27	
	TSW	Male	28.41	9.07	0.19
		Female	32.48	10.92	
Knee	IS	Male	14.49	8.99	0.70
		Female	15.46	8.52	
	MS	Male	12.09	6.51	0.22
		Female	15.17	9.01	
	TS	Male	24.91	12.11	0.66
		Female	23.53	10.32	
	ISW	Male	30.39	13.73	0.84
		Female	29.63	11.96	
	MSW	Male	46.21	16.15	0.50
		Female	49.24	15.17	
	TSW	Male	10.98	7.18	0.43
		Female	12.81	8.07	
Ankle	IS	Male	1.97	3.82	0.55
		Female	2.65	3.95	
	MS	Male	7.97	6.97	0.01[a]
		Female	12.16	4.86	
	TS	Male	9.53	10.55	0.01[a]
		Female	**15.16**	**5.96**	
	ISW	Male	0.84	5.99	0.87
		Female	1.19	7.67	
	MSW	Male	8.27	6.79	0.08
		Female	10.68	3.86	
	TSW	Male	3.53	3.80	0.99
		Female	3.50	5.21	
Coronal					
Pelvis	IS	Male	−0.25	3.26	0.93
		Female	−0.16	3.60	
	MS	Male	−3.03	7.29	0.86
		Female	−3.33	5.26	
	TS	Male	1.17	3.97	0.82
		Female	0.92	3.70	
	ISW	Male	2.52	4.83	0.78
		Female	2.16	4.31	
	MSW	Male	4.69	5.56	0.92
		Female	4.55	4.62	
	TSW	Male	1.81	3.74	0.70
		Female	1.40	3.59	
Hip	IS	Male	−0.64	5.00	0.67
		Female	0.12	6.32	
	MS	Male	−4.69	9.08	0.62
		Female	−3.45	8.27	
	TS	Male	−1.20	4.85	0.34
		Female	0.62	6.87	
	ISW	Male	−1.47	4.70	0.33
		Female	1.52	11.40	
	MSW	Male	0.29	5.32	0.59
		Female	1.37	7.23	
	TSW	Male	0.21	4.64	0.67
		Female	0.98	6.41	

(*continued on next page*)

Table 6 (*continued*)

	Parameters	Gender	Mean	SD	p-value
Knee	IS	Male	6.06	6.79	0.09
		Female	2.25	7.88	
	MS	Male	7.31	6.71	0.10
		Female	3.88	7.16	
	TS	Male	6.88	5.61	0.004[a]
		Female	0.77	7.23	
	ISW	Male	7.02	7.73	0.00003[a]
		Female	−3.04	7.69	
	MSW	Male	7.99	5.36	0.002[a]
		Female	1.07	7.71	
	TSW	Male	5.51	6.12	0.06
		Female	1.67	7.18	
Ankle	IS	Male	3.91	6.24	0.15
		Female	1.58	5.30	
	MS	Male	−1.91	4.35	0.11
		Female	−3.71	3.59	
	TS	Male	6.26	7.33	0.93
		Female	6.41	5.03	
	ISW	Male	6.65	8.82	0.81
		Female	7.10	5.77	
	MSW	Male	5.25	5.83	0.76
		Female	5.70	4.62	
	TSW	Male	4.52	5.93	0.56
		Female	3.57	5.35	
Transverse					
Pelvis	IS	Male	1.98	6.34	0.83
		Female	1.65	4.69	
	MS	Male	2.79	6.09	0.58
		Female	3.65	5.09	
	TS	Male	−1.64	6.48	0.93
		Female	−1.51	4.48	
	ISW	Male	−2.45	6.01	0.98
		Female	−2.40	4.80	
	MSW	Male	−2.90	6.65	0.98
		Female	−2.93	5.34	
	TSW	Male	−0.23	5.35	0.71
		Female	0.26	4.22	
Hip	IS	Male	−5.23	11.88	0.03[a]
		Female	−12.28	10.27	
	MS	Male	−5.06	13.03	0.0004[a]
		Female	−16.62	9.83	
	TS	Male	2.53	20.69	0.0001[a]
		Female	−13.66	10.61	
	ISW	Male	−0.93	11.78	0.00003[a]
		Female	−14.31	9.60	
	MSW	Male	0.04	12.93	0.0002[a]
		Female	−13.01	10.52	
	TSW	Male	−3.06	11.56	0.006[a]
		Female	−13.40	12.65	
Knee	IS	Male	−6.06	12.13	0.18
		Female	−1.73	10.48	
	MS	Male	−6.27	11.56	0.02[a]
		Female	1.46	10.40	
	TS	Male	−7.89	12.69	0.01[a]
		Female	0.25	10.50	
	ISW	Male	−4.91	13.38	0.71
		Female	−3.56	11.79	
	MSW	Male	−8.29	11.98	0.11
		Female	−2.64	12.04	
	TSW	Male	−12.05	11.37	0.02[a]
		Female	−3.81	11.36	
Ankle	IS	Male	−17.87	6.30	0.47
		Female	−16.17	8.41	
	MS	Male	−17.63	6.36	0.29
		Female	−14.55	10.66	
	TS	Male	−17.41	8.01	0.27
		Female	−14.29	9.86	
	ISW	Male	−16.43	8.47	0.32
		Female	−13.56	10.12	
	MSW	Male	−19.64	6.77	0.64
		Female	−20.92	10.04	
	TSW	Male	−19.23	6.05	0.30
		Female	−16.13	11.01	

IS: initial stance, MS: midstance, TS: terminal stance, ISW: initial swing, MSW: mid swing, TSW: terminal swing.

[a] Indicates significant difference.

between genders for gait speed (4.57 cm/s), Step length (0.01 m), and step time (0.01 s) was lower than Hollman et al.[21] normative data for gait speed (7 cm/s), lower for Step length (0.09 m) and step time (0.04 s).

Kerrigan et al.[23] found a statistically significant difference between male and female stride length and cadence. In their study, the average stride length was 1.33 ± 0.10 m for young healthy females and 1.38 ± 0.12 m for males. The average cadence for females was 120.40 ± 10 steps/min and 112.80 ± 9 steps/min for males. Our study showed no significant difference in stride length and cadence between genders of the OA adult population but showed a significant difference in stance time between males and females.

In the investigation conducted[24] on young women with a mean age of 21.1, the mean gait speed measured at 137 ± 11 cm/s, stride length at 1.41 ± 0.09 m, and step length at 0.64 ± 0.04 m were observed to be greater than the corresponding values in our study. This discrepancy indicates that there may be a decline in spatio-temporal parameters as age increases, particularly in individuals with osteoarthritis (OA) knees. Tas et al.[25] reported significant differences in step length, step time, and stance phase length. No such significant difference observed in our study may be due to bilateral involvement of OA knees.

4.2. GPS and MAP

In the MAP, each column corresponds to a kinematic variable, and its height reflects the root mean square average difference across time between a specific gait cycle and the average gait cycle of individuals without gait pathology.[16] A more favorable MAP is indicated by a lower value. In our study, a significant difference was observed in GPS and hip internal/external rotation in which females had higher scores as compared to males signified worse gait motion in females. Significantly higher MAP observed in knee flexion/extension for grade 4 suggested worse knee movement in the gait cycle compared to grade 3 OA knee.

4.3. Joint angles

Bytyqi et al.[26] documented an initial contact (IC) flexion of 19°, maximum flexion, and extension during stance at 22.4° and 7.6°, respectively. The maximum flexion during the swing phase was reported as 48.2°, while the adduction at IC was 5.7°, and the external rotation at IC was recorded as 0.3°. Our study shows lower flexion at IC (male −14.4°, female −15.4°), higher Max flexion at stance (male −24.9, female-23.5), higher max extension at stance (male −12°, female −15.1°), similar observation for max flexion during swing (male −46.2, female −49.2), higher adduction at IC for male −6.06 and lower for female −2.25, higher external rotation at IC (male- 6.06°, female −1.73°).

Kerrigan et al.[23] study on normative young adults (mean age 28.5 years) discovered that females exhibited notably higher hip flexion and reduced knee extension before initial contact, coupled with increased knee flexion during the pre-swing phase. The Study shows a significant difference in peak hip flexion (female - 26.2 ± 5°; male - 23 ± 4.7°). Near significant difference for knee flexion (female - 61.5 ± 6.2°; male - 59.4 ± 5°) and ankle plantar flexion (female −22.2 ± 7.5°; male −19.3 ± 6.3°). Our study shows no significant difference for hip flexion in the mid-swing phase (female 32.5 ± 11.2); male 29.9 ± 7.9), Peak knee flexion (female 49.2 ± 15.1; male 46.2 ± 16.1), and ankle plantar-flexion in initial swing phase (female - 1.1 ± 7.6; male - 0.84 ± 5.9). Positive values in the ankle plantarflexion phase suggest actual dorsi-flexion of the foot during the initial contact phase of the gait cycle.

Oberg et al.[20] conducted a study on normal subjects, categorizing them by age using electrogoniometers. They provided reference data on joint angle parameters at slow, normal, and fast speeds. In the sagittal plane, for individuals aged 60–69 years, males exhibited a mean knee joint angle of 22.0° during midstance and 67.1° during the swing phase at normal gait speed. Females in the same age group showed a midstance angle of 18.1° and a swing phase angle of 60.2°. In contrast, our study indicates lower values for sagittal knee midstance (male - 12.26°; female −15.24°) and mid-swing (male - 45.03°; female - 49.76°), suggesting restricted knee range of motion during the gait cycle due to osteoarthritis-related changes in the knee.

According to our study findings in Tables 5 and 6, males exhibit greater extension during the stance phase and increased flexion in the swing phase compared to females. Minimal differences are observed in the sagittal plane for grade 3 and grade 4 OA. Males consistently demonstrate higher adduction angles across the entire gait cycle, while females exhibit slight abduction during the initial swing phase. Grade 4 OA knees display a higher adduction angle than grade 3 OA knees. Throughout the gait cycle, males display greater external rotation, whereas females show slight internal rotation in the late stance phase. Grade 3 OA knees exhibit more external rotation during the swing phase compared to grade 4 OA knees.

This study has a few limitations. Firstly, the sample size is restricted due to challenges in recruiting elderly osteoarthritic patients. Secondly, the study does not include a statistical comparison of results with normative data. Future researchers could consider enlarging the sample size and placing emphasis on parameters that exhibit significant differences.

5. Conclusions

The research established normative data specifically for the elderly population dealing with knee OA. Focusing on joint angles, temporospatial parameters, GPS, and MAP, the study sheds light on the nuanced differences in gait patterns between genders and individuals with varying degrees of OA severity. Spatio-temporal parameters, including gait speed, cadence, and stance time, were meticulously examined, exposing meaningful distinctions between severe and moderate OA. Additionally, GPS and MAP analyses provided granular insights into specific kinematic variables contributing to the overall pathology of gait. Joint angle comparisons offered a detailed understanding of the biomechanical alterations associated with knee OA, showcasing significant differences in ankle, knee, and hip movements between individuals with severe and moderate OA, as well as between genders. The implications of the findings are substantial, emphasizing the necessity for tailored interventions for individuals contending with knee OA. By establishing reference values for this specific population, research equips orthopedic surgeons and physiotherapists with invaluable insights, enabling the development of more precise and effective interventions. Ultimately, the study contributes to enhancing the overall quality of life for individuals grappling with knee OA.

Funding/sponsorship

None.

Ethical approval and patient consent

The study has been conducted following the ethical principles mentioned in the Declaration of Helsinki (2013).

CRediT authorship contribution statement

Sanket Tanpure: Conceptualization, Software, Formal analysis, Writing – original draft. **Ashish Phadnis:** Methodology, Validation. **Taral Nagda:** Methodology, Validation. **Chasanal Rathod:** Validation, Supervision. **Rohan Kothurkar:** Writing – review & editing. **Ajay Chavan:** Data collection, Resources.

Declaration of competing interest

None.

Acknowledgements

None.

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