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The Biomechanical Effects of Cross-Legged Sitting on the Lower Limbs and the Implications in Rehabilitation

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Abstract: Background: While cross-legged-sitting (CLS) posture is widely practised in some communities, its biomechanical effect on the lower limbs is not clear. This study aimed to investigate whether CLS would affect biomechanical parameters in lower limbs during gait. Methods: Thirty healthy volunteers participated in this study and performed CLS on ground for 20 min. Their modes of gait were compared before and after CLS regarding to temporospatial parameters and the kinetic and kinematic parameters in the lower limb joints. Results: CLS significantly increased walking cadence and speed. In kinematics, the ranges of motion for almost all lower limb joints were increased after CLS except the knee in sagittal plane. In kinetics, the medial and lateral forces increased significantly after CLS in the lower limb joints, e.g., the hip posterior force was increased more than 14% on both sides. Furthermore, all hip, knee, and ankle powers were increased significantly after CLS. Conclusion: CLS has a positive impact on the biomechanical parameters of almost all lower limb joints except the knee flexion/extension angle and internal/external joint moments. Therefore, CLS can be used in the daily routine and in any rehabilitation programme to improve the biomechanical parameters of the lower extremities.

Keywords: cross-legged-sitting; gait; joint kinematics; joint kinetics; posture

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1. Introduction

Sitting is the most common posture in daily life and different postures in sitting may bring in different effects on the lower limbs, but the effects are still not predictive. So far, most studies have focused on sitting on chair [1–6]. In sitting, the balanced coordination between the several body segments could perform a significant role in protecting the limb and joints from injuries and maintaining body postures from deformities particularly during the sitting position as sitting takes more than half of the daily activities [3,7]. Although most of the postural deformities, such as kyphosis, lordosis, and scoliosis, might be caused by improper sitting posture and duration, attempting to preserve a healthy and balanced sitting posture with normal spinal and pelvic alignments can perform a significant role in protecting the skeletal functions and improving the quality of life [8–10]. To compensate for the adverse effects of improper sitting positions regardless of the sitting duration, yoga can be beneficial for decreasing the pain level, improving equilibrium, and increasing the muscular strength of the lower limbs. This is to protect the body posture and avoid improper sitting-associated complications, particularly in spinal vertebrae regardless of which sitting type is used [11–13]. For this reason, it is considered that more studies should be completed regarding what is proper sitting posture and how the balance could be protected during prolonged sitting [14,15]. In short, the research on sitting may provide us the information on whether a posture would be benefit to personal health or cause bad effect on the skeleton so that clinicians develop prevention means.

The appropriate and suitable sitting posture performs a significant role in maintaining the proper general posture during all activities of daily living. This is because sitting behaviour can influence the discomfort level, pressure distribution, and muscular status of the back and lower limbs, which might be responsible for balanced and coordinated walking [10,15].

According to the activity level, prolonged sitting or standing might lead to some lower limb problems, such as plantar fasciitis, knee flexors, and ankles plantar flexor muscles, particularly gastrocnemius and soleus, e.g., increasing pressure at the medial and lateral arch, hallux, mid-foot, hind-foot, and forefoot. Thus, the gait biomechanical parameters will be affected negatively because of the long-time of sitting without any activities or locomotion [16].

For this reason, Waters and Dick (2014) and Waclawski et al. (2015) discussed that the excessive activation of the gluteus Medius muscle during prolonged static postures, such as sitting, can alter not only the spinal alignment, but also the biomechanical parameters of the lower limb during the dynamic posture, such as walking, by increasing the abduction range of motion at the hip joint and causing the muscular fatigue or walking with the pronated foot to compensate for the excessive pain [17,18].

An example of the influences of sitting posture on the body biomechanics is that after 20 min of forward-leaning sitting, the body shifted the centre of gravity anteriorly, causing equilibrium disturbance and increasing level of discomfort at the hip joint during the walking [5]. Although the 7–10 min of backward-leaning sitting can the hip and knee kinematics, especially if the knee is at the same level as the hip, it can also increase the hip and knee muscular spasm [19]. However, the 10 min of upright cross-legged sitting (sitting on a chair with one leg over another) can cause many adverse side effects that might occur during changing the position from sitting to standing or during locomotion, such as disturbance in the Gluteus Maximus, Medius and minimums pressure, or incoordination in the angle between the horizontal and inlet planes of the pelvis [10].

Although the cross-legged-sitting (CLS) posture has been widely practised as a part of daily routine in some communities, little research has focused on the effects of CLS on the lower limbs in terms of biomechanics. As CLS usually takes long duration, e.g., hours, some people have the doubts that CLS would cause negative effects on the lower limbs or joints, especially on the knee. Therefore, the research questions are whether the long duration of CLS would biomechanically affect the lower limb joints and gait. If so, what kind of effects would CLS have on the lower limbs and joints? These questions have not been answered by previous studies.

In this study, the research hypothesis was that CLS could alter the temporospatial parameters, and kinematic and kinetic parameters of the lower limbs during gait. The aim of this study was to investigate the biomechanical effects of CLS on the lower limb joints by comparing gait parameters, kinematic and kinetic parameters in two situations (1) before CLS, i.e., baseline, and (2) after 20 min of CLS. Hopefully, this study would contribute new understanding to the knowledge of this field.

2. Materials and Methods

This study took place in the Motion and Gait Analysis Laboratory at the Tayside Orthopaedics and Rehabilitation Technology (TORT) Centre, Ninewells Hospital and Medical School. Data were collected in the period between September 2021 and September 2022. Ethical approval was obtained from the School of Medicine and Life Sciences Research Ethics Committee at the University of Dundee (SMED REC Number 21/74).

Before starting the data collection, the participants read the Participant Information Sheet, then signed the consent form after he/she understood all the study protocol and agreed to participate. Participants were required to wear a short and a T-shirt so that researchers could adhere the retro-reflective markers directly on their skin using a double-sided adhesive tape. Each participant understood that there was no risks or negative side effects in the study as all techniques are used routinely in clinical practice. In general, a single session of data collection took approximately 90 min, including a period of CLS for 20 min, and 2 times of collection of gait data before and after CLS.

2.1. Subject Data

A suitable group of participants (30 healthy adults, 15 males and 15 females) with the age group between 18–40 years were invited to participate in this study. All participants were able to walk, do activities of daily living, and communicate with others independently without suffering from abnormal spinal curvatures or any musculoskeletal diseases, particularly in the lower limb. People who are disabled or obese, and pregnant women were excluded from this study. In addition, any volunteer suffered from any cardiovascular disorders, musculoskeletal diseases, postural deformities, neuropathy, fractures, or use of orthosis or prosthesis was excluded.

2.2. Laboratory Equipment

Vicon® Nexus Motion Capture system (Vicon Motion System Ltd., Oxford, UK) was used to capture reflective marker data. The marker data was calculated using a Plug-in-Gait model to produce gait parameters, e.g., walking speed and cadence, and kinematic and kinetic joint parameters, e.g., joint angles, forces, moments, and powers, etc. A total of 15 infrared digital cameras with a strobe head unit, an optical filter, and a distinct video camera, including cables and lenses, in each are the main components of the Vicon® Nexus Motion Capture system. All cameras relate to Nexus software version 2.12.0 and are directed or focused on the capture volume area to be able to capture images at 200 Hz.

The four force platforms (Advanced Mechanical Technology, Inc., Watertown, MA, USA, AMTI, BP 600 mm $\times$ 400 mm) were arranged in mixed and used to collect the ground reaction force in all three directions at the same time with a frequency of 1000 Hz so that the kinetic parameters in the lower limbs could be obtained using inverse dynamics. Before the data collection starts, the calibration of both Vicon and AMTI systems was carried out using both manual and automatic ways to achieve good quality capturing, verify or check the vertical and horizontal forces, and avoid a higher image error. All force plates were checked in all directions by comparing the weight converted to Newton with the calculated force. The changes should not exceed increases or decreases of 10 N. Otherwise, the calibration must be repeated with the lab technicians helping.

2.3. Data Collection

As a part of the data collection, the anthropometric measurements for each participant were collected, including the right and left leg length, knee width, ankle width, the distance between right and left Anterior Superior Iliac Spine bony prominences, body mass, and height. In addition, some information, such as age, gender, and what is the dominant leg (the leg is preferred to stand on) were recorded. Thereafter, the Retro-reflective spherical (14 mm diameter with a small base.) markers for Vicon® 3D motion capture were adhered to the skin surface over specific bony prominences using a double-sided adhesive tape following the Vicon Clinical Management Marker System, lower limb model as in Figure 1.

After preparing the participant with the Retro-reflective, the participant was asked to stand over the force platform in a position called T-pose, in which the participant should raise their arms to be in the abduction position while their legs slightly separated. The main reason for T-pose capturing is to make sure all markers are noticeable on the Vicon® software. Then, the subject was asked to walk along the walkway at their normal walking speed without taking any consideration of the force plate location to avoid any subconsciousness or alteration that could happen in the gait biomechanics. The walking data was captured using the Vicon® 3D motion capture system in a combination with the force platforms. In CLS for 20 min, each participant performed his/her natural/comfortable cross-legged-sitting on the carpeted ground regardless of which leg was “on top” and without considering the participant’s leg dominance (Figure 2). The participants could play on mobile phones or read books while all markers were attached to the lower limbs.

The participants were required to sit for at least 20 min and were not allowed to go toilet. The walking data including joint kinematics and kinetics were collected after participants completed 20 min of CLS immediately to save the effects of the CLS on the biomechanics of the lower limbs.

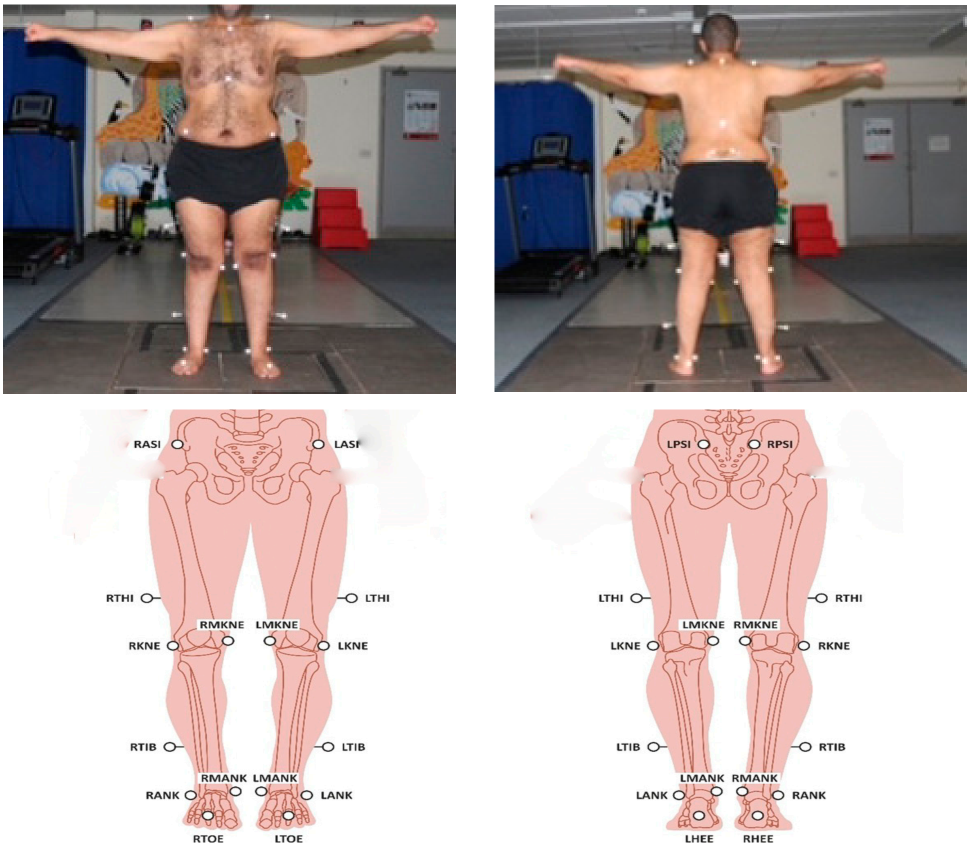

Figure 1. Marker placement (**upper**) according to Vicon® Plug-in-Gait Model (**lower**). Note: Subject with markers: front view (**left**) and back view (**right**); the shoulder and trunk markers used for balance analysis.

Figure 2. The cross-legged sitting position.

In data analysis, all markers were labelled, and two gait cycles were defined for each trial, one for each side of leg. In each stride, three events were detected manually, including the first heel strike followed by foot-off (the first step), then the foot strike again (the second step). We used Vicon Nexus to watch the stick figure during gait in the workspace and to use the ground reaction force vector to determine when the foot was in contact/released contact for a given trial. A total of 10 trials of walking were collected for each participant, 5 before CLS and 5 after CLS. As a whole, 300 trails of walking for

30 participants (150 before CLS and 150 after) were collected. Out of 300 collected walking trials, 236 good trials were labelled to be ready for extraction and analysis (118 before CLS and 118 after CLS), and some trials with marker gaps or without force platform were removed.

2.4. Check Marker Placement

As the markers were attached on the lower limbs during data collection after T-pose measurement, it is necessary to check if the marker placement would be shifted during data collection, especially for the wand marker L/RTHI and L/RTIB during CLS. It was observed that the wand markers used have a fixed base which stops the wand markers from getting knocked out of alignment. In addition, using 10 randomly selected subjects, we measured the distances of KNE-THI during the T-pose and last dynamic trials, and the distances of ANK-TBI during the T-pose and last dynamic trials to compare the distance changes between the T-pose and last trials. It was found that the mean change of distances of KNE-THI were approximately 0.10 (SD 3.37) (mm), the absolute mean changes 2.40 (SD 2.23) mm, relatively mean changes 0.13% (SD 1.92%), and relatively mean absolute 1.40% (SD 1.23%). For the distance of ANK-TBI, the mean change of distances between T-pose and last trials were approximately 0.53 (SD 2.79) (mm), the absolute mean changes 2.08 (SD 1.81) mm, relatively mean changes 0.21% (SD 1.74%), and relatively mean absolute 1.31% (SD 1.08%). The distance change is very close within minimum accepted error. In other words, the marker placement was not significantly shifted.

2.5. Data Analysis

The demographic descriptive statistic variables, including gender (male or female), body mass (kg), body mass index (km/m^2), height (cm), age (years), and the dominant leg for each participant (right or left), were collected and analysed using Excel prior to getting the basic results.

The following variables were calculated using Vicon Plug-in-Gait® model and exported as csv file format. Then, an in-house program made in Matlab® was used to extract useful information from the csv files. After data processing, the variables were obtained as below:

1. Temporospatial parameters including Cadence (step/min), Walking speed (m/s), Stride and Step time (s), and Stride and Step length (m).
2. All lower limb kinematic variables (Degree) in all planes; (sagittal, frontal and transverse) for the hip, knee and ankle joints.
3. All lower limb kinetic variables in all directions (Anterior/Posterior, Medial/Lateral and Vertical):
    I. Hip, knee and ankle joint force (N/kg);
    II. Hip, knee and ankle joint moment (Nm/kg);
    III. Hip, knee and ankle joint power (W/kg).

2.6. Statistical Analysis

The SPSS® version 28 (SPSS® Inc., Chicago, IL, USA) was used for statistical analysis of the data. Then, splitting data depending on the side is a necessary step to get clear results for each right and left leg during the walking before and after CLS. The data was analysed using the Repeated Measures that are branched from the General Linear Model in SPSS. This method allows us to input repeated measures and compare the variables as a pair. This method also allowed us to input other factor, e.g., gender as interactive factor and body mass index as covariate factor. The compared parameters were put into Dependent Variables, then the Group (before and after CLS) was put in Fixed Factor. The main factor between groups should be in the within-subject variable, while gender was the between-subject factor, and body mass index was in the covariates space. This is to get the difference between the two situations (before and after CLS), and to display means according to selected factors. The $p < 0.05$ was as a significant level. Then, the estimated mean and standard errors with the significance level (p-value) were copied to excel to create suitable graphs that can explain the results properly. The significance level (p-value) between the two groups of data was dealt with as: $p \leq 0.05$ symbolized as * (significant difference), $p \leq 0.01$ symbolized as ** (high confidence in the difference), $p \leq 0.001$ symbolized as *** (extremely high confidence in the difference) and $p > 0.05$ (no significant difference)

2.7. Power Analysis

To check if the sample size was fine, we carried out a posteriori power analysis. Given that β is 0.2, i.e., power = 1 − β = 0.8 or 80%, α = 0.05, clinical difference 2.5 deg in the range of motion in knee flexion/extension and standard deviation 5 deg from the data collected in this study, the sample size should be 31 [20]. Therefore, though this study had a reasonably sample size, it is still considered as a pilot study.

3. Results

3.1. Demography and Gait Parameters

The mean of the demographic measures was as in Table 1: body weight 70.42 kg, body mass index (BMI) 25.06 km/m^2, height 167 cm, and age 26.8 years in Table 1.

Table 1. Demographic measures.

	Mean SD		Minimum	Maximum
Gender (M/F)	30 (15/15)			
Body mass (kg)	70.42	3.52	42.40	123
Height (cm)	167	1.54	150	185
BMI (km/m^2)	25.06	1.04	16.77	41.87
Age (years)	26.86	0.86	20	39

3.2. Temporospatial Parameters

Using the data derived from 30 participants, it appears that the spatial parameters, including the cadence and walking speed, increased significantly after CLS, while the temporal parameters, including the step and stride times, were significantly decreased after CLS for both right and left legs as in Table 2.

3.3. Kinematic Parameters

The transverse hip range of motion (ROM) significantly increased during the gait cycle as a whole after CLS compared to before for both the right and left sides. However, the flexion angle increased noticeably only in the right hip, while the left hip had a visible grown adduction angle during the walking after CLS. As whole, the ROM in coronal plane increased roughly 12% due to the CLS with valgus posture in the knee and 5% due to the abducting posture in the hip as in Figure 3 and Table 3. It is found that hip rotation in transverse plane is most significantly increased.

Considering the knee kinematics, all the right and left knee joint ROM in the sagittal plane (Flexion/Extension) declined noticeably during the walking after CLS compared to before. However, the knee joint ROM in the coronal plane (Valgus/Varus) and transverse plane (Medial/Lateral Rotation) increased significantly after CLS on both the right and left sides after CLS compared to before, as in Table 4 and Figure 4, where it is found that knee rotation in the transverse plane is significantly shifted.

Table 2. Temporospatial parameters.

Parameter	Side		Mean	Std. Error	Sig.
Cadence (step/min)	Left	After CLS Before CLS	110.388 103.760	0.504 0.414	$p < 0.001$ ***
	Right	After CLS Before CLS	110.511 104.297	0.474 0.407	$p < 0.001$ ***
Walking Speed (m/s)	Left	After CLS Before CLS	1.149 1.081	0.006 0.005	$p < 0.001$ ***
	Right	After CLS Before CLS	1.152 1.085	0.006 0.005	$p < 0.001$ ***
Stride Length (m)	Left	After CLS Before CLS	1.248 1.249	0.002 0.002	0.521
	Right	After CLS Before CLS	1.250 1.247	0.003 0.002	0.238
Step Length (m)	Left	After CLS Before CLS	0.632 0.630	0.001 0.001	0.242
	Right	After CLS Before CLS	0.630 0.628	0.002 0.001	0.202
Stride Time (s)	Left	After CLS Before CLS	1.102 1.169	0.005 0.004	$p < 0.001$ ***
	Right	After CLS Before CLS	1.099 1.162	0.004 0.004	$p < 0.001$ ***
Step Time (s)	Left	After CLS Before CLS	0.555 0.590	0.003 0.002	$p < 0.001$ ***
	Right	After CLS Before CLS	0.553 0.582	0.002 0.002	$p < 0.001$ ***

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$ for all tables.

Table 3. Hip Joint Angle in sagittal, coronal, and transverse planes.

Plane	Side			Mean (Degree)	Std. Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Sagittal	Left	Flexion	Before CLS After CLS	27.18 27.52	0.68 0.69	25.84 26.15	28.53 28.88	0.192
		Extension	Before CLS After CLS	−15.11 −14.94	0.68 0.71	−16.45 −16.34	−13.76 −13.55	0.436
		ROM	Before CLS After CLS	42.29 42.46	0.38 0.37	41.54 41.73	43.04 43.19	0.457
	Right	Flexion	Before CLS After CLS	26.12 26.75	0.64 0.67	24.85 25.44	27.39 28.07	0.003 **
		Extension	Before CLS After CLS	−14.77 −14.47	0.62 0.68	−16.00 −15.81	−13.54 −13.13	0.137
		ROM	Before CLS After CLS	40.88 41.22	0.37 0.36	40.15 40.51	41.62 41.92	0.173
Coronal	Left	Abduction	Before CLS After CLS	5.50 5.26	0.37 0.35	4.77 4.57	6.23 5.95	0.188
		Adduction	Before CLS After CLS	−7.80 −8.16	0.33 0.35	−8.45 −8.86	−7.15 −7.47	0.018 *
		ROM	Before CLS After CLS	13.30 13.42	0.36 0.33	12.59 12.78	14.00 14.07	0.481
	Right	Abduction	Before CLS After CLS	6.39 6.18	0.35 0.38	5.69 5.44	7.09 6.92	0.184
		Adduction	Before CLS After CLS	−6.88 −6.85	0.35 0.35	−7.56 −7.54	−6.19 −6.16	0.884
		ROM	Before CLS After CLS	13.27 13.03	0.37 0.32	12.54 12.40	14.00 13.67	0.23
Transverse	Left	Max External Rotation	Before CLS After CLS	−10.01 −11.42	0.82 1.14	−11.62 −13.68	−8.39 −9.15	0.034 *
		Min External Rotation	Before CLS After CLS	−29.24 −31.97	0.86 1.04	−30.94 −34.03	−27.53 −29.90	$p < 0.001$ ***
		ROM	Before CLS After CLS	19.23 20.55	0.47 0.52	18.30 19.53	20.17 21.58	$p < 0.001$ ***
	Right	Max (Lateral or External Rotation)	Before CLS After CLS	−5.09 −4.24	0.80 0.89	−6.68 −6.00	−3.49 −2.48	0.029 *
		Min (Lateral or External Rotation)	Before CLS After CLS	−26.08 −26.55	0.88 0.95	−27.83 −28.43	−24.33 −24.68	0.193
		ROM	Before CLS After CLS	21.00 22.31	0.51 0.55	19.99 21.23	22.01 23.40	0.001 ***

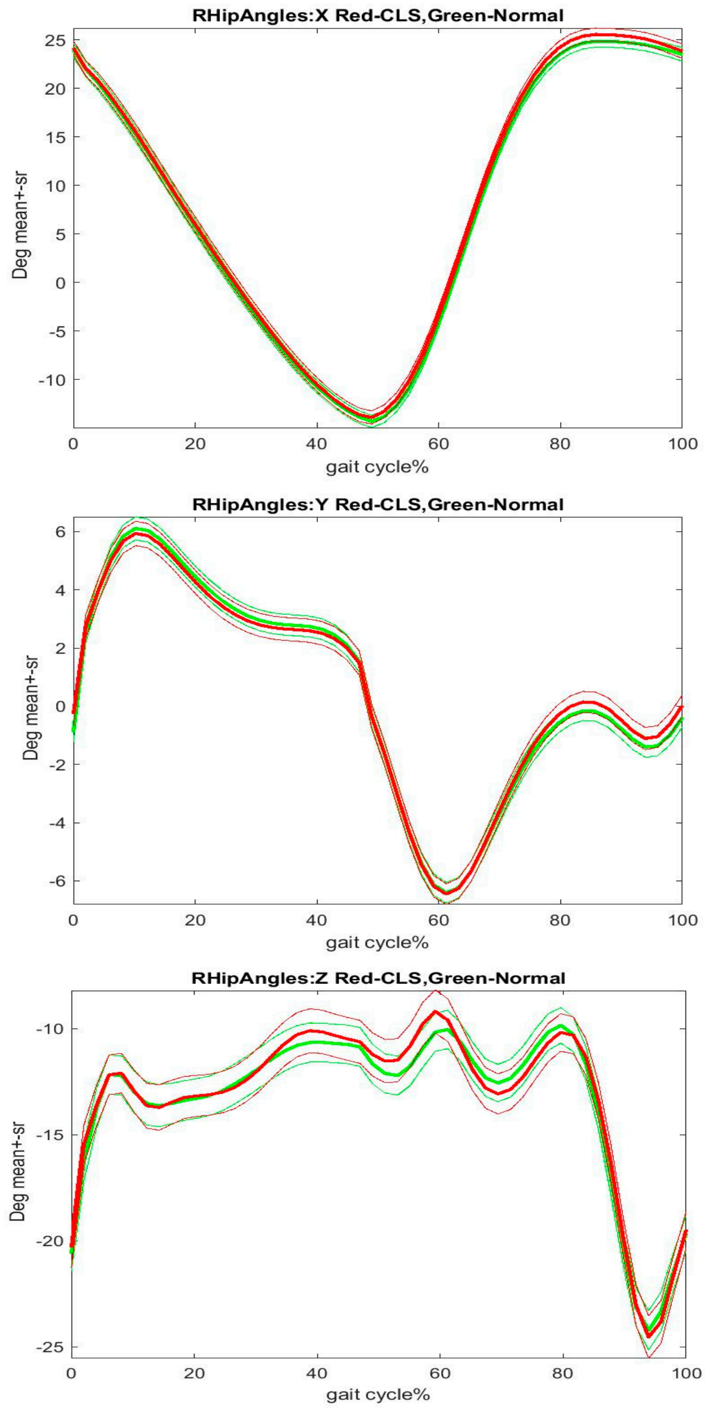

Figure 3. Hip angles' comparison between before and after CLS in right side. Note: Green: before CLS, Red: after CLS; X, Y, and Z: the sagittal, coronal, and transverse planes. Thickness lines: mean, fined lines: standard error of mean. The curve patterns were plotted using right side 118 pair trials for before and after CLS, and some trails with gaps were removed. As the trails used to plot figures were resampled to 50 frames, there are slightly numeric differences between figures and tables. Nevertheless, the figures show the trends between before and after CLS.

Table 4. Knee Joint Angle in sagittal, coronal, and transverse planes.

Plane	Side			Mean (Degree)	Std. Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Sagittal	Left	Flexion	Before CLS After CLS	51.448 51.434	0.581 0.539	50.297 50.367	52.599 52.500	0.968
		Extension	Before CLS After CLS	−5.810 −4.591	0.393 0.474	−6.588 −5.531	−5.032 −3.652	0.001 ***
		ROM	Before CLS After CLS	57.258 56.025	0.492 0.563	56.283 54.910	58.233 57.140	0.002 **
	Right	Flexion	Before CLS After CLS	51.320 51.564	0.510 0.567	50.310 50.440	52.331 52.687	0.427
		Extension	Before CLS After CLS	−6.252 −5.138	0.413 0.445	−7.070 −6.018	−5.435 −4.257	$p < 0.001$ ***
		ROM	Before CLS After CLS	57.572 56.701	0.408 0.419	56.764 55.871	58.381 57.531	0.003 **
Coronal	Left	Varus	Before CLS After CLS	4.459 4.869	0.447 0.524	3.574 3.832	5.343 5.907	0.048 *
		Valgus	Before CLS After CLS	−12.206 −14.108	0.593 0.700	−13.381 −15.495	−11.032 −12.722	0.002 **
		ROM	Before CLS After CLS	16.665 18.978	0.567 0.759	15.542 17.475	17.788 20.480	$p < 0.001$ ***
	Right	Varus	Before CLS After CLS	4.684 4.913	0.568 0.604	3.560 3.717	5.809 6.109	0.276
		Valgus	Before CLS After CLS	−8.972 −9.359	0.420 0.502	−9.803 −10.353	−8.141 −8.364	0.147
		ROM	Before CLS After CLS	13.657 14.272	0.575 0.578	12.518 13.127	14.795 15.417	0.023 *
Transverse	Left	Internal Rotation	Before CLS After CLS	11.579 13.951	0.532 0.941	10.526 12.087	12.632 15.815	0.005 **
		External Rotation	Before CLS After CLS	−9.198 −7.883	0.627 1.075	−10.440 −10.013	−7.956 −5.753	0.120
		ROM	Before CLS After CLS	20.777 21.834	0.585 0.552	19.618 20.740	21.936 22.928	0.006 **
	Right	Internal Rotation	Before CLS After CLS	11.284 13.095	0.542 0.949	10.210 11.215	12.357 14.975	0.022 *
		External Rotation	Before CLS After CLS	−8.349 −7.498	0.689 1.046	−9.713 −9.569	−6.985 −5.427	0.294
		ROM	Before CLS After CLS	19.633 20.593	0.575 0.597	18.493 19.411	20.772 21.775	0.013 **

Although the ankle transverse ROM elevated on both the right and left sides during the walking after CLS compared to before, only the significant difference was in the left ankle, in which the ROM increased around 4.4% after CLS ($p = 0.022$) as in Table 5.

3.4. Kinetic Parameters

- Force

The general force range of the hip joint in all directions increased significantly during the walking after CLS compared to before for both sides. To specify, the posterior force, medial and lateral force, and the tension and compression force were increased significantly for both right and left hip joints after CLS compared to before. As a result, from CLS, the hip force in posterior direction increased roughly 3% as Table 6.

- Moment

Only the left hip joint had a significant increase in terms of flexion and abduction moments when comparing the gait before CLS to after. In contrast, there is no significant change between the gait before and after CLS according to the rotational moment as in Table 9. Regarding the knee moment, the noticeable increase was in the left knee valgus moment during the walking after CLS. However, both right and left knee joints had a significant increase in the flexion moment after CLS compared to before, as in Figure 6 and

Table 10. Only the right ankle plantar flexion moment and left ankle abduction moment were increased significantly after CLS compared to before, as in Table 11.

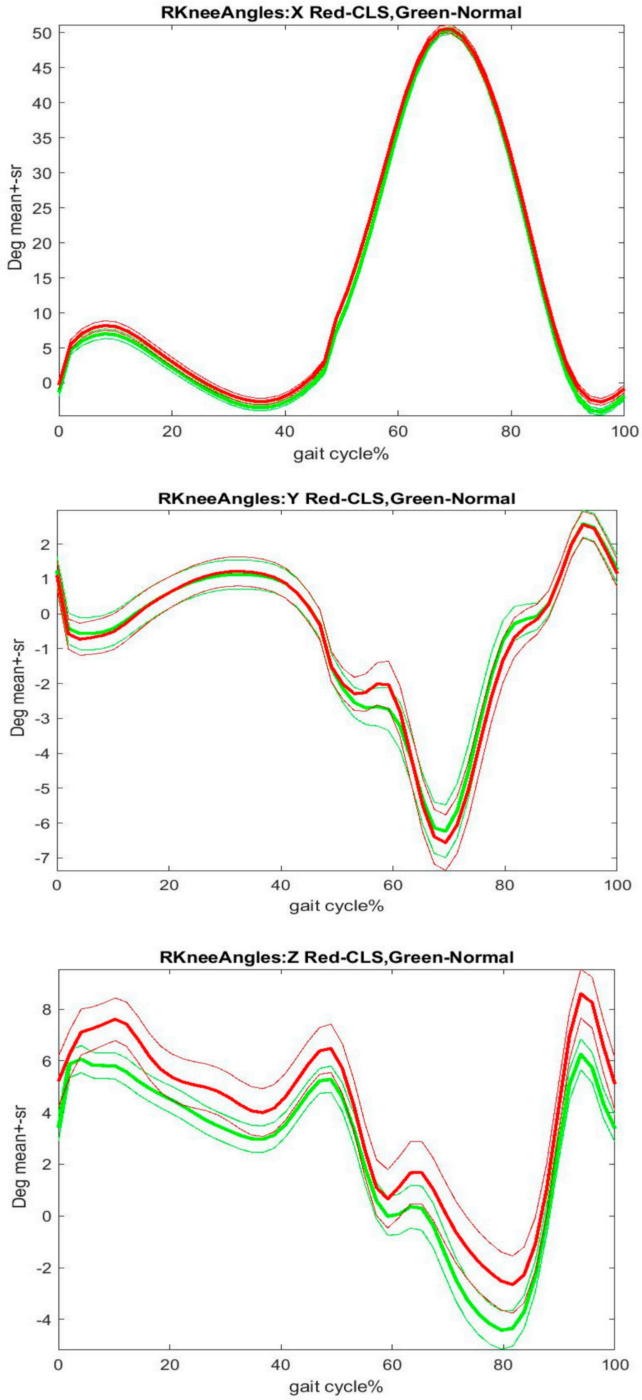

Figure 4. Knee angles' comparison between before and after CLS in right side. Note: Green: before CLS, Red: after CLS; X, Y, and Z: the sagittal, coronal, and transverse planes. Thickness lines: mean, fine lines: standard error of mean. The curve patterns were plotted using right side 118 pair trials for before and after CLS, and some trails with gaps were removed. As the trails used to plot figures were resampled to 50 frames, there are slightly numeric differences between figures and tables. Nevertheless, the figures show the trends between before and after CLS.

Table 5. Ankle Joint Angle in sagittal, coronal, and transverse planes.

Plane	Side			Mean (Degree)	Std. Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Sagittal	Left	Dorsiflexion	Before CLS After CLS	10.9 10.5	0.3 0.4	10.2 9.6	11.6 11.3	0.166
		Plantar flexion	Before CLS After CLS	−24.9 −25.2	0.7 0.8	−26.2 −26.7	−23.6 −23.7	0.587
		ROM	Before CLS After CLS	35.8 35.7	0.6 0.7	34.6 34.4	37.0 37.0	0.817
	Right	Dorsiflexion	Before CLS After CLS	11.2 11.1	0.4 0.5	10.5 10.2	11.9 12.0	0.828
		Plantar flexion	Before CLS After CLS	−23.6 −24.0	0.6 0.8	−24.8 −25.7	−22.5 −22.4	0.510
		ROM	Before CLS After CLS	34.8 35.1	0.6 0.8	33.6 33.6	36.0 36.7	0.508
Coronal	Left	Supination (Adduction)	Before CLS After CLS	4.2 4.2	0.4 0.4	3.4 3.5	4.9 5.0	0.624
		Pronation (Abduction)	Before CLS After CLS	−2.9 −2.8	0.2 0.2	−3.3 −3.2	−2.6 −2.4	0.238
		ROM	Before CLS After CLS	7.1 7.0	0.4 0.4	6.4 6.3	7.8 7.7	0.410
	Right	Supination (Adduction)	Before CLS After CLS	6.7 7.3	0.3 0.4	6.1 6.5	7.3 8.0	0.002 **
		Pronation (Abduction)	Before CLS After CLS	−3.0 −2.6	0.1 0.2	−3.2 −3.0	−2.8 −2.3	0.013 **
		ROM	Before CLS After CLS	9.7 9.9	0.3 0.3	9.1 9.2	10.4 10.5	0.279
Transverse	Left	Inversion	Before CLS After CLS	21.2 21.3	0.7 0.8	19.8 19.7	22.6 23.0	0.842
		Eversion	Before CLS After CLS	5.1 4.6	0.6 0.8	4.0 3.0	6.3 6.1	0.384
		ROM	Before CLS After CLS	16.1 16.8	0.4 0.4	15.3 16.0	16.9 17.5	0.022 *
	Right	Inversion	Before CLS After CLS	22.7 20.7	0.7 1.2	21.2 18.3	24.1 23.2	0.022 *
		Eversion	Before CLS After CLS	6.0 4.0	0.7 1.1	4.5 1.8	7.4 6.2	0.009 **
		ROM	Before CLS After CLS	16.7 16.8	0.4 0.4	15.9 16.0	17.4 17.5	0.866

Regarding the knee joints, the left knee achieved a significant increase in the values of the anterior, medial and lateral, and tension and compression forces in all three directions. However, only the lateral and tension forces were increased significantly in the right knee when comparing the gait after CLS with before as in Table 7 and Figure 5.

Considering the ankle joint, both the right and left ankles had a noticeable increase in terms of compression, and medial and anterior forces after CLS, while only the left ankle had a significant increase in the lateral force and a significant decrease in the posterior force values after CLS compared to before as in Table 8.

Table 6. Hip Joint Force in Anterior/Posterior, Medial/Lateral, and Tension/Compression directions.

Direction	Side			Mean (N/Kg)	Std. Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Anterior/Posterior	Left	Anterior	After CLS Before CLS	3.15 3.17	0.05 0.05	3.05 3.07	3.24 3.27	0.461
		Posterior	After CLS Before CLS	−1.17 −1.02	0.07 0.06	−1.30 −1.13	−1.04 −0.91	$p < 0.001$ ***
		RoF	After CLS Before CLS	4.32 4.19	0.07 0.07	4.17 4.06	4.46 4.33	0.029 *
	Right	Anterior	After CLS Before CLS	3.13 3.13	0.05 0.05	3.04 3.03	3.23 3.23	0.913
		Posterior	After CLS Before CLS	−1.27 −1.11	0.06 0.06	−1.39 −1.23	−1.14 −0.99	0.006 **
		RoF	After CLS Before CLS	4.40 4.24	0.07 0.07	4.25 4.10	4.54 4.38	0.015 *

Table 6. *Cont.*

Direction	Side			Mean (N/Kg)	Std. Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Medial/Lateral	Left	Medial	After CLS Before CLS	0.93 0.87	0.04 0.04	0.86 0.79	1.00 0.95	0.015 *
		Lateral	After CLS Before CLS	−0.50 −0.38	0.04 0.02	−0.58 −0.43	−0.42 −0.33	$p < 0.001$ ***
		RoF	After CLS Before CLS	1.43 1.25	0.06 0.04	1.32 1.16	1.54 1.34	$p < 0.001$ ***
	Right	Medial	After CLS Before CLS	0.34 0.30	0.03 0.03	0.28 0.25	0.40 0.35	0.006 **
		Lateral	After CLS Before CLS	−1.06 −0.99	0.04 0.04	−1.14 −1.07	−0.98 −0.91	$p < 0.001$ ***
		RoF	After CLS Before CLS	1.39 1.29	0.04 0.04	1.31 1.21	1.48 1.38	$p < 0.001$ ***
Tension/Compression	Left	Tension	After CLS Before CLS	2.18 2.11	0.02 0.02	2.14 2.08	2.21 2.14	$p < 0.001$ ***
		Compression	After CLS Before CLS	−9.15 −8.97	0.06 0.05	−9.27 −9.07	−9.04 −8.88	$p < 0.001$ ***
		RoF	After CLS Before CLS	11.33 11.08	0.07 0.06	11.20 10.97	11.46 11.19	$p < 0.001$ ***
	Right	Tension	After CLS Before CLS	2.15 2.07	0.02 0.02	2.11 2.04	2.19 2.09	$p < 0.001$***
		Compression	After CLS Before CLS	−9.14 −8.98	0.06 0.05	−9.25 −9.09	−9.03 −8.87	0.008 **
		RoF	After CLS Before CLS	11.29 11.05	0.07 0.06	11.16 10.92	11.42 11.17	$p < 0.001$ ***

Table 7. Knee Joint Force in Anterior/Posterior, Medial/Lateral, and Tension/Compression directions.

Direction	Side			Mean (N/Kg)	Std.Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Anterior/Posterior	Left	Anterior	After CLS Before CLS	3.44 3.33	0.05 0.04	3.34 3.25	3.54 3.42	0.005 **
		Posterior	After CLS Before CLS	−1.18 −1.15	0.03 0.04	−1.24 −1.22	−1.12 −1.08	0.484
		RoF	After CLS Before CLS	4.62 4.49	0.06 0.06	4.50 4.37	4.73 4.60	0.009 **
	Right	Anterior	After CLS Before CLS	3.35 3.32	0.04 0.05	3.27 3.23	3.43 3.42	0.406
		Posterior	After CLS Before CLS	−1.18 −1.17	0.04 0.04	−1.25 −1.25	−1.11 −1.09	0.668
		RoF	After CLS Before CLS	4.53 4.49	0.05 0.06	4.44 4.38	4.63 4.60	0.366
Medial/Lateral	Left	Medial	After CLS Before CLS	1.15 1.08	0.04 0.03	1.08 1.01	1.22 1.14	0.009 **
		Lateral	After CLS Before CLS	−0.40 −0.36	0.03 0.02	−0.45 −0.41	−0.34 −0.31	0.021 *
		RoF	After CLS Before CLS	1.55 1.44	0.03 0.03	1.48 1.37	1.61 1.50	$p < 0.001$ ***
	Right	Medial	After CLS Before CLS	0.31 0.28	0.02 0.02	0.27 0.25	0.35 0.31	0.169
		Lateral	After CLS Before CLS	−1.27 −1.16	0.05 0.03	−1.36 −1.22	−1.17 −1.10	0.003 **
		RoF	After CLS Before CLS	1.58 1.44	0.05 0.03	1.49 1.38	1.67 1.50	$p < 0.001$ ***

Table 7. *Cont.*

Direction	Side			Mean (N/Kg)	Std.Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Tension/Compression	Left	Tension	After CLS Before CLS	1.03 0.98	0.01 0.01	1.01 0.96	1.06 1.01	$p < 0.001$ ***
		Compression	After CLS Before CLS	−10.09 −9.96	0.05 0.04	−10.20 −10.05	−9.99 −9.88	0.006 **
		RoF	After CLS Before CLS	11.13 10.95	0.06 0.05	11.00 10.85	11.25 11.04	0.001 ***
	Right	Tension	After CLS Before CLS	1.04 0.98	0.01 0.01	1.01 0.95	1.06 1.00	$p < 0.001$ ***
		Compression	After CLS Before CLS	−10.08 −9.98	0.05 0.05	−10.18 −10.08	−9.98 −9.89	0.084
		RoF	After CLS Before CLS	11.12 10.96	0.06 0.05	11.00 10.85	11.23 11.06	0.012 **

Table 8. Ankle Joint Force in Anterior/Posterior, Medial/Lateral, and Tension/Compression directions.

Direction	Side			Mean (N/Kg)	Std. Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Tension/Compression	Left	Tension	After CLS Before CLS	10.80 10.72	0.05 0.04	10.70 10.65	10.90 10.80	0.112
		Compression	After CLS Before CLS	−0.39 −0.37	0.01 0.01	−0.41 −0.38	−0.38 −0.36	0.001 ***
		RoF	After CLS Before CLS	11.19 11.09	0.05 0.04	11.09 11.01	11.30 11.18	0.051 *
	Right	Tension	After CLS Before CLS	10.80 10.76	0.05 0.05	10.71 10.66	10.90 10.85	0.412
		Compression	After CLS Before CLS	−0.40 −0.37	0.01 0.01	−0.42 −0.38	−0.38 −0.35	$p < 0.001$ ***
		RoF	After CLS Before CLS	11.20 11.12	0.05 0.05	11.10 11.03	11.30 11.22	0.166
Medial/Lateral	Left	Medial	After CLS Before CLS	1.17 1.10	0.04 0.04	1.09 1.03	1.26 1.17	0.005 **
		Lateral	After CLS Before CLS	−0.20 −0.17	0.02 0.02	−0.23 −0.20	−0.17 −0.14	0.001 ***
		RoF	After CLS Before CLS	1.38 1.28	0.04 0.04	1.30 1.21	1.46 1.35	$p < 0.001$ ***
	Right	Medial	After CLS Before CLS	0.30 0.24	0.02 0.02	0.25 0.20	0.35 0.28	$p < 0.001$ ***
		Lateral	After CLS Before CLS	−0.97 −0.95	0.04 0.04	−1.05 −1.02	−0.88 −0.87	0.515
		RoF	After CLS Before CLS	1.27 1.18	0.04 0.03	1.18 1.11	1.35 1.25	0.016 *
Anterior/Posterior	Left	Anterior	After CLS Before CLS	2.67 2.48	0.05 0.05	2.57 2.39	2.78 2.57	$p < 0.001$ ***
		Posterior	After CLS Before CLS	−0.68 −0.78	0.03 0.04	−0.74 −0.84	−0.62 −0.71	0.003 **
		RoF	After CLS Before CLS	3.36 3.25	0.06 0.06	3.24 3.14	3.47 3.36	0.027 *
	Right	Anterior	After CLS Before CLS	2.59 2.49	0.05 0.05	2.48 2.40	2.70 2.59	0.026 *
		Posterior	After CLS Before CLS	−0.71 −0.70	0.03 0.04	−0.78 −0.78	−0.65 −0.63	0.832
		RoF	After CLS Before CLS	3.30 3.20	0.05 0.05	3.20 3.10	3.41 3.29	0.057

Table 9. Hip Joint Moment in Flexion/Extension, Adduction/Abduction, and Internal/External Rotation directions.

Direction	Side			Mean (Nm/Kg)	Std. Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Flexion/Extension	Left	Flexion	After CLS Before CLS	0.86 0.80	0.03 0.03	0.80 0.75	0.92 0.86	0.017 *
		Extension	After CLS Before CLS	−1.47 −1.45	0.02 0.02	−1.52 −1.50	−1.43 −1.41	0.158
		ROM	After CLS Before CLS	2.34 2.25	0.04 0.03	2.27 2.19	2.41 2.32	0.011 **
	Right	Flexion	After CLS Before CLS	0.87 0.82	0.03 0.03	0.82 0.76	0.93 0.89	0.060
		Extension	After CLS Before CLS	−1.40 −1.38	0.02 0.02	−1.44 −1.42	−1.36 −1.34	0.143
		ROM	After CLS Before CLS	2.27 2.21	0.03 0.04	2.20 2.13	2.34 2.28	0.034 *
Adduction/Abduction	Left	Adduction	After CLS Before CLS	0.63 0.62	0.02 0.02	0.60 0.59	0.66 0.65	0.439
		Abduction	After CLS Before CLS	−0.27 −0.23	0.02 0.01	−0.31 −0.25	−0.24 −0.21	0.001 ***
		ROM	After CLS Before CLS	0.90 0.84	0.02 0.02	0.85 0.81	0.95 0.88	0.018 *
	Right	Adduction	After CLS Before CLS	0.75 0.75	0.02 0.02	0.72 0.71	0.79 0.78	0.555
		Abduction	After CLS Before CLS	−0.21 −0.21	0.01 0.01	−0.23 −0.23	−0.19 −0.19	0.807
		ROM	After CLS Before CLS	0.97 0.96	0.02 0.02	0.93 0.92	1.00 0.99	0.492
Internal/External Rotation	Left	Internal Rotation	After CLS Before CLS	0.09 0.09	0.01 0.01	0.08 0.08	0.10 0.10	0.967
		External Rotation	After CLS Before CLS	−0.15 −0.15	0.01 0.01	−0.16 −0.16	−0.13 −0.14	0.524
		ROM	After CLS Before CLS	0.24 0.24	0.01 0.01	0.23 0.23	0.25 0.25	0.405
	Right	Internal Rotation	After CLS Before CLS	0.15 0.15	0.01 0.01	0.13 0.13	0.16 0.16	0.553
		External Rotation	After CLS Before CLS	−0.09 −0.10	0.01 0.01	−0.11 −0.11	−0.08 −0.08	0.445
		ROM	After CLS Before CLS	0.24 0.25	0.01 0.01	0.23 0.23	0.25 0.26	0.077

Table 10. Knee Joint Moment in Flexion/Extension, Adduction/Abduction, and Internal/External Rotation directions.

Direction	Side			Mean (Nm/kg)	Std. Error	95% ConfidenceInterval		Sig.
						Lower Bound	Upper Bound	
Flexion/Extension	Left	Flexion	After CLS Before CLS	0.68 0.62	0.02 0.02	0.63 0.58	0.73 0.66	$p < 0.001$ ***
		Extension	After CLS Before CLS	−0.44 −0.44	0.01 0.01	−0.46 −0.46	−0.41 −0.41	0.925
		ROM	After CLS Before CLS	1.12 1.05	0.03 0.03	1.06 1.00	1.17 1.11	0.003 **
	Right	Flexion	After CLS Before CLS	0.62 0.56	0.02 0.02	0.57 0.52	0.66 0.60	$p < 0.001$ ***
		Extension	After CLS Before CLS	−0.46 −0.44	0.01 0.02	−0.49 −0.48	−0.43 −0.41	0.163
		ROM	After CLS Before CLS	1.08 1.00	0.02 0.02	1.03 0.96	1.13 1.05	0.001 ***

Table 10. *Cont.*

Direction	Side			Mean (Nm/kg)	Std. Error	95% ConfidenceInterval		Sig.
						Lower Bound	Upper Bound	
Varus/Valgus	Left	Varus	After CLS Before CLS	0.43 0.43	0.01 0.01	0.41 0.40	0.45 0.45	0.475
		Valgus	After CLS Before CLS	−0.12 −0.11	0.01 0.00	−0.13 −0.12	−0.11 −0.10	0.012 **
		ROM	After CLS Before CLS	0.55 0.54	0.01 0.01	0.53 0.52	0.57 0.56	0.039 *
	Right	Varus	After CLS Before CLS	0.45 0.44	0.01 0.01	0.43 0.42	0.48 0.47	0.231
		Valgus	After CLS Before CLS	−0.10 −0.09	0.00 0.00	−0.11 −0.10	−0.09 −0.08	0.215
		ROM	After CLS Before CLS	0.55 0.54	0.01 0.01	0.53 0.51	0.58 0.56	0.108
Internal/External Rotation	Left	Internal Rotation	After CLS Before CLS	0.09 0.09	0.01 0.01	0.07 0.07	0.10 0.10	0.963
		External Rotation	After CLS Before CLS	−0.10 −0.10	0.01 0.01	−0.11 −0.12	−0.09 −0.09	0.138
		ROM	After CLS Before CLS	0.18 0.19	0.00 0.00	0.18 0.18	0.19 0.20	0.007 **
	Right	Internal Rotation	After CLS Before CLS	0.15 0.15	0.01 0.01	0.13 0.13	0.16 0.16	0.999
		External Rotation	After CLS Before CLS	−0.05 −0.05	0.00 0.00	−0.05 −0.06	−0.04 −0.05	0.131
		ROM	After CLS Before CLS	0.19 0.20	0.01 0.01	0.18 0.19	0.21 0.21	0.343

Table 11. Ankle Joint Moment in Dorsi/Plantar Flexion, Adduction/Abduction, and Internal/External Rotation directions.

Direction	Side			Mean (Nm/Kg)	Std. Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Dorsi/Plantar Flexion	Left	Dorsiflexion	After CLS Before CLS	1.29 1.30	0.01 0.01	1.27 1.28	1.32 1.32	0.676
		Plantar flexion	After CLS Before CLS	−0.25 −0.23	0.01 0.01	−0.27 −0.25	−0.23 −0.22	0.101
		ROM	After CLS Before CLS	1.54 1.53	0.01 0.01	1.52 1.51	1.57 1.56	0.203
	Right	Dorsiflexion	After CLS Before CLS	1.33 1.33	0.01 0.01	1.30 1.31	1.35 1.35	0.918
		Plantar flexion	After CLS Before CLS	−0.24 −0.22	0.01 0.01	−0.25 −0.23	−0.22 −0.21	0.025 *
		ROM	After CLS Before CLS	1.56 1.55	0.01 0.01	1.54 1.52	1.59 1.57	0.160
Adduction/Abduction	Left	Adduction	After CLS Before CLS	0.15 0.15	0.01 0.01	0.14 0.14	0.16 0.16	0.658
		Abduction	After CLS Before CLS	−0.08 −0.07	0.00 0.00	−0.09 −0.08	−0.07 −0.06	0.020 *
		ROM	After CLS Before CLS	0.22 0.22	0.00 0.01	0.21 0.21	0.23 0.23	0.191
	Right	Adduction	After CLS Before CLS	0.12 0.12	0.01 0.01	0.11 0.11	0.13 0.14	0.631
		Min (Abduction)	After CLS Before CLS	−0.05 −0.05	0.00 0.00	−0.06 −0.06	−0.05 −0.04	0.709
		ROM	After CLS Before CLS	0.17 0.17	0.01 0.01	0.16 0.16	0.18 0.19	0.713

Table 11. *Cont.*

Direction	Side			Mean (Nm/Kg)	Std. Error	95% Confidence Interval		Sig.
						Lower Bound	Upper Bound	
Internal/External Rotation	Left	Internal Rotation	After CLS Before CLS	0.08 0.08	0.01 0.01	0.07 0.07	0.09 0.09	0.496
		External Rotation	After CLS Before CLS	−0.11 −0.11	0.01 0.01	−0.12 −0.12	−0.10 −0.10	0.534
		ROM	After CLS Before CLS	0.19 0.19	0.00 0.00	0.18 0.18	0.20 0.20	0.938
	Right	Internal Rotation	After CLS Before CLS	0.16 0.15	0.01 0.01	0.15 0.13	0.18 0.16	0.130
		External Rotation	After CLS Before CLS	−0.05 −0.05	0.00 0.00	−0.05 −0.06	−0.04 −0.04	0.661
		ROM	After CLS Before CLS	0.21 0.20	0.01 0.01	0.20 0.19	0.22 0.21	0.094

- Power

All the hip, knee, and ankle power had increased dramatically in terms of Range of power during the walking after CLS compared to before as in Table 12. In summary, the results provided the general trend of group aged between 20 and 40 years old after CLS.

Table 12. Hip, Knee and Ankle power.

Estimates							
	Side		Mean (W/Kg)	Std. Error	95% Confidence Interval		Sig.
					Lower Bound	Upper Bound	
Left hip	Max	After CLS Before CLS	1.46 1.28	0.06 0.05	1.35 1.19	1.57 1.38	$p < 0.001$ ***
	Min	After CLS Before CLS	−1.46 −1.33	0.05 0.05	−1.56 −1.43	−1.36 −1.24	0.003 **
	RoP	After CLS Before CLS	2.92 2.61	0.09 0.08	2.74 2.46	3.09 2.77	$p < 0.001$ ***
Right hip	Max	After CLS Before CLS	1.52 1.28	0.06 0.04	1.41 1.20	1.62 1.37	$p < 0.001$ ***
	Min	After CLS Before CLS	−1.57 −1.42	0.07 0.05	−1.71 −1.53	−1.43 −1.32	0.01 **
	RoP	After CLS Before CLS	3.09 2.70	0.10 0.08	2.89 2.55	3.28 2.86	$p < 0.001$ ***
Left knee	Max	After CLS Before CLS	0.74 0.73	0.03 0.03	0.68 0.66	0.80 0.79	0.758
	Min	After CLS Before CLS	−1.49 −1.31	0.06 0.06	−1.61 −1.41	−1.38 −1.20	$p < 0.001$ ***
	RoP	After CLS Before CLS	2.23 2.03	0.08 0.07	2.08 1.89	2.38 2.18	0.001 ***
Right knee	Max	After CLS Before CLS	0.81 0.74	0.04 0.04	0.74 0.67	0.89 0.81	0.050 *
	Min	After CLS Before CLS	−1.44 −1.26	0.06 0.06	−1.55 −1.37	−1.33 −1.16	$p < 0.001$ ***
	RoP	After CLS Before CLS	2.25 2.01	0.08 0.08	2.09 1.85	2.42 2.16	0.001 ***
Left ankle	Max	After CLS Before CLS	3.71 3.46	0.08 0.07	3.55 3.32	3.88 3.61	$p < 0.001$ ***
	Min	After CLS Before CLS	−0.80 −0.76	0.03 0.02	−0.85 −0.81	−0.75 −0.71	0.095
	RoP	After CLS Before CLS	4.52 4.23	0.09 0.09	4.33 4.06	4.70 4.39	$p < 0.001$ ***
Right ankle	Max	After CLS Before CLS	3.72 3.45	0.08 0.08	3.56 3.29	3.88 3.60	$p < 0.001$ ***
	Min	After CLS Before CLS	−0.81 −0.83	0.03 0.03	−0.86 −0.89	−0.75 −0.78	0.175
	RoP	After CLS Before CLS	4.53 4.28	0.09 0.09	4.34 4.10	4.71 4.46	$p < 0.001$ ***

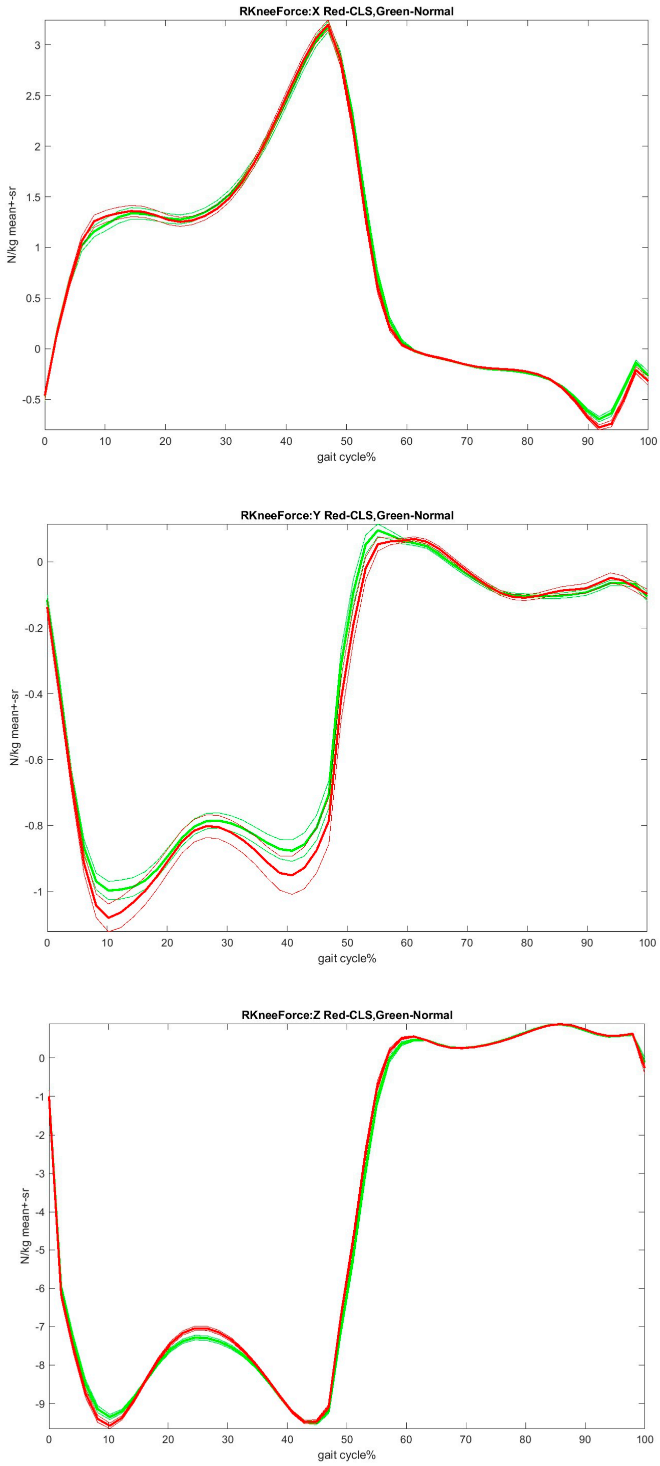

Figure 5. Knee forces' comparison between before and after CLS in right side. Note: Green: before CLS, Red: after CLS; X, Y, and Z: the anterior-posterior, medial-lateral, and vertical directions. Thickness lines: mean, fine lines: standard error of mean. The curve patterns were plotted using right side 118 pair trials for before and after CLS, and some trails with gaps were removed. As the trails used to plot figures were resampled to 50 frames, there are slightly numeric differences between figures and tables. Nevertheless, the figures show the trends between before and after CLS.

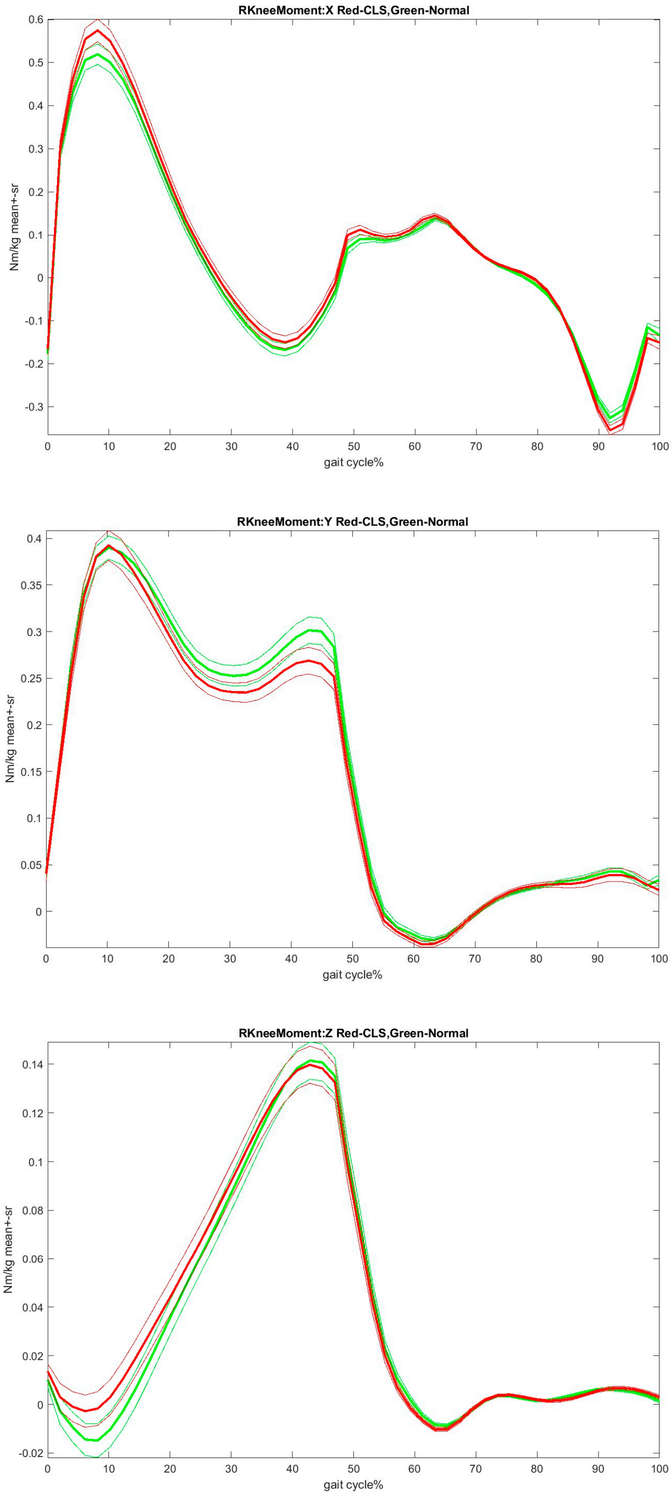

Figure 6. Knee moments' comparison between before and after CLS in right side. Note: Green: before CLS, Red: after CLS; X, Y, and Z: the sagittal, coronal, and transverse planes. Thickness lines: mean, fine lines: standard error of mean. The curve patterns were plotted using right side 118 pair trials for before and after CLS, and some trails with gaps were removed. As the trails used to plot figures were resampled to 50 frames, there are slightly numeric differences between figures and tables. Nevertheless, the figures show the trends between before and after CLS.

4. Discussion

To our best knowledge, this study is the first one focused on the biomechanical parameters of CLS; we cannot find any previous studies to compare with. Therefore, the discussion was written depending on comparing the current study results with the biomechanical effects of osteoarthritis (OA) and some different sitting positions, such as yoga and forward and backward leaning sitting on the lower extremities.

4.1. Temporospatial Discussion

The temporospatial results demonstrated in this study did not match the OA parameters that had been provided by Ismailidis et al. (2020) [21]. To clarify, increasing cadence, walking speed, and stride length with decreasing step and stride duration that happened during the walking after CLS was contradictory to Ismailidis et al. (2020) [21]. Compared to yoga posture, increasing the walking speed, step, and stride length, and decreasing the stride duration during walking after CLS is consistent with research that was completed by Zettergren et al. (2011), Wang et al. (2016), and DiBenedetto et al. (2005) regarding the effect of the yoga exercise on improving the temporospatial parameters [11,13,22]. However, considering the difference in the temporospatial parameters, particularly the number of steps per minute and the walking speed, walking after CLS was opposite to what happened after the yoga exercises programme that was discussed in the Hainsworth et al. (2018) study, in which the waking cadence and velocity were noticeably decreased after yoga exercise [14]. For this reason, CLS can be considered as a healthy posture depending on its effect on the temporospatial parameters, which is in reverse to the effect of some joint problems, such as OA, but resembles the effect of healthy positions, such as yoga.

4.2. Kinematic Discussion

The main findings demonstrated in this study match with what Na et al. (2018) reported regarding the gait biomechanical parameters that might help therapists to predict the occurrence of knee osteoarthritis [23]. To clarify, the fluctuating in the knee kinematic parameters between declining the sagittal plane ROM, particularly the extension angle, and raising the adduction angle in the frontal plane could be considered as the early symptoms of knee osteoarthritis OA. Moreover, decreasing knee flexion angle was considered by Ismailidis et al. (2020) as one of the main walking kinematic changes that happen to the knee joint among osteoarthritis patients (OA) [21]. However, we did not find any increase in the ankle dorsiflexion angle or decrease in the ankle plantar flexion angle during the gait after CLS. This is opposite to the gait biomechanical findings of osteoarthritis patients (OA) that had been stated by Ismailidis et al. (2020) [21].

Although the hip abduction angle changed after CLS without any significant difference, it was the opposite point to what Waters and Dick (2014) reported regarding the effect of improper sitting posture on the lower extremities that could be avoided by changing the posture from static to dynamic regularly [18]. Therefore, Karakolis et al. (2016) and Major and Vézina (2015) advised the employees to separate each hour of static posture with a few minutes of dynamic movements to decrease the level of discomfort and protect the postural alignment [24,25].

Comparing the CLS parameters with backward sitting by Hofmann et al. (2016) and upright cross-legged sitting (one leg over another) by Lee and Yoo (2011) and Jung et al. (2020), it is determined that increasing hip flexion angle after CLS is consistent with the effect of the mentioned unhealthy postures [2,10,19]. However, decreasing the hip adduction angles and sagittal knee angles during walking after 20 min of CLS is inconsistent with what has been found during 7–10 min of backward leaning and 1–10 min of upright cross-legged sitting.

On the other hand, the effect of CLS findings in the current study is directly in line with the characteristics of forward-leaning posture that had been completed for some volunteers for 7–20 min and considered an unhealthy position by Hallman et al. (2016), Darwish et al. (2019), and Nishida et al. (2020) [7,26,27]. In detail, it is claimed that increased hip sagittal ROM, particularly the flexion angle, that happened during the forward-leaning sitting position, could be the main cause of considering this position as unhealthy due to increasing the lumbar flexion that will be occurred accordingly.

Unlike the yoga position that had been analysed by Hainsworth et al. (2018) and DiBenedetto et al. (2005) [11,14], CLS can increase the hip extension angle, ankle plantar flexion angle in the sagittal plane, and the knee varus angle in the frontal plane, while the hip abduction angle and ankle dorsiflexion angle decrease during walking after CLS compared to before. However, the significant increase in the knee varus angle after CLS is consistent with what Shultz et al. (2011) stated regarding the biomechanical parameters of obese people's gait [12].

In line with the ideas stated by Waclawski et al. (2015) and Martin et al. (2014) [16,17], decreasing knee kinematics, particularly knee flexion, ROM can be considered a negative effect of improper sitting. This point is consistent with the main effects of CLS on the knee in the current study. However, decreasing the ankle plantar flexion angles can be dealt with as one characteristics of an unhealthy sitting position. This point did not match with what happened in the ankle after CLS in the current study. Therefore, based on the kinematic literature, there is no match between CLS influences with any influences of unhealthy sitting postures or any primary predicting signs of lower limb problems particularly knee osteoarthritis [2,10,18,19,23]. However, the only similarity point with improper sitting is that decreasing knee sagittal plane kinematics, which is responsible mainly for flexion/extension movement [16,17]. However, the study reported by Karakolis et al. (2016) varies with the current study in terms of decreasing knee kinematics. In detail, the increase in knee flexion ROM in the sagittal plane might be increased after any unhealthy sitting position, particularly among obese patients [24]. In addition, the increase in the hip external rotation during walking after CLS ties well with the study completed by Armstrong et al. (2016) regarding the effect of obesity on postural alignment, particularly on the hip joint [1].

4.3. Kinetic Discussion

The significant increase after CLS in the hip and knee moments in all directions contrasts with the view indicated by Darwish et al. (2019), which can be summarized as any static or dynamic posture that leads to a decrease in the lower limb moments particularly at the hip joint can affect the spinal alignment negatively [26]. Therefore, the biomechanical result of the current study might provide evidence to consider the CLS as a healthy sitting posture as it can increase the knee moment in the Flexion/Extension and Varus/Valgus directions which may lead to preserving the correct spinal alignment. However, the decrease in the internal/external rotational moment at the hip joint, which can be considered one of the positive impacts of the CLS on the body posture, is inconsistent with what was found by Freddolini et al. (2014) during the unsupported sitting posture [28].

Unlike the yoga position that had been analysed by Hainsworth et al. (2018) and DiBenedetto et al. (2005) [11,14], CLS can increase the hip and knee abduction/adduction moment, while the hip internal rotation moment was decreased during walking after CLS compared to before.

The main findings demonstrated in this study match with what Na et al. (2018) reported regarding the gait biomechanical parameters of knee osteoarthritis (OA) [23]. Furthermore, the higher adduction moment in the valgus/varus direction and flexion moment in the flexion/extension direction that occurred after CLS might be similar to the main characteristics of walking biomechanics caused by knee osteoarthritis (OA).

Contrary to the findings of Na et al. (2018), our results demonstrate that there is a significant increase during the walking after CLS in the ROM of knee flexion/extension moment, which is opposite to what Na et al. (2018) reported as one of the knee osteoarthritis (OA) biomechanics [23].

The study reported by Karakolis et al. (2016) corresponds with the current study findings in terms of increasing knee force after CLS [24]. In detail, it is considered that the knee force in all directions might be increased after any unhealthy sitting position, particularly among obese patients.

CLS within 20 min was similar to what happened during the gait after yoga exercise in terms of increasing all the hip, knee, and ankle power significantly (DiBenedetto et al., 2005) [11].

Therefore, depending on the kinetic literature, increasing the values of the knee moment in the Flexion/Extension and Varus/Valgus directions, raising the power values of all lower limb joints and decreasing the hip internal/external rotational moment during the gait after CLS can be considered as healthy signs of the CLS posture on the lower limbs [23,26,28]. However, only the increasing knee force can be considered an unhealthy sign of CLS on the knee joint [24].

4.4. Limitation

This study has some limitations including lack of different age groups. A small sample size is also a limitation, indicating that a full study with larger sample size should be carried out in the future. In addition, CLS with longer duration than 20 min has not been tested in this study, and thus the effect of longer duration in CLS on the lower limbs could be a study in the future.

4.5. Future Studies

This study should be completed with the different age groups, including children, adults, and elders. In addition, it should be applied to real patients to assess the biomechanical parameters and general condition prognosis. The effects of CLS on the lower limbs in the elderly are still not predictive, especially in the long duration. Additionally, it is necessary to do this work by considering the daily life routine to compare the long-term experienced CLS with those who used CLS occasionally according to the effect on the biomechanics of the lower limb joints.

4.6. Clinical Relevance

Since there are no previous studies of the effect of CLS on the biomechanics of the lower extremities, although this position has been widely used as a part of daily routine in some communities, the results of this research study can be regarded as a contribution to this new field. The CLS can be safely involved in the daily routine and in any rehabilitation programme to improve the biomechanical parameters of the lower extremities. Clinically, CLS's effect on the lower limbs and walking is predictive for the special age group as in this study.

5. Conclusions

The cross-legged sitting (CLS) was analysed biomechanically by comparing the walking in two situations: (1) before CLS, and (2) after 20 min of CLS for 30 healthy participants. The variables for comparison included the temporospatial measures, and kinetic and kinematic parameters.

CLS can affect the gait temporospatial parameters positively by increasing the cadence, making the walking faster than before, and decreasing the stride and step time. In addition, the kinematic ROM for almost all lower limb joints have increased after CLS compared to before in all planes (sagittal, frontal, and transverse) except knee sagittal ROM (flexion/extension), which decreased significantly after CLS.

Considering the kinetic parameters, the medial and lateral forces increased significantly in terms of RoF during the walking after CLS compared to before in almost all lower limb joints including the hip, knee, and ankle in both sides. Moreover, the left knee and right ankle joints were similar in terms of increasing the anterior force after CLS, while the posterior force was increased in both sides of hip joints and decreased significantly in only the left ankle. Furthermore, the compression force increased significantly on both sides of almost all lower limb joints except the right knee. While the tension force improved noticeably on only right hip, left hip, and left knee joint.

When comparing the walking before CLS with after according to the moment values, it is pointed out that the flexion/extension moment was risen significantly after CLS in the hip and knee joints in terms of ROM, while only the plantar flexion moment increased in the right ankle during the walking after CLS compared to before. However, it is noticed that only the left leg had a significant increase in the knee valgus moment, and hip and ankle abduction moment. Relate to the rotation direction, the left knee had a significant decline in terms of the internal/external rotational moment.

Regarding the power values of all lower extremity joints, it is stated that all hip, knee, and ankle joints are similar in terms of increasing the RoP during the gait after 20 min of CLS compared to before.

Generally, increasing the spatiotemporal parameters including the gait speed with the same step length resulting in higher cadence, changes in joint force, moment, and power may indicate some compensation mechanisms due to ligament/muscle stretch. Therefore, CLS can be safely involved in the daily routine and in any rehabilitation programme to improve the biomechanical parameters of the lower extremities. CLS does not need any prevention means if personal sitting duration is short, e.g., 20 min. However, for a long duration in CLS, the effects on the lower limbs and walking are still not predictive.

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