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Gait Analysis Before and After Total Knee Replacement

Abstract- *Total knee replacement is a surgical procedure for treatment of knee Osteoarthritis, Rheumatoid arthritis and posttraumatic arthritis. The main goals of TKR are relieve the pain, restore function, mobility and restore normal limb alignment for the patients. The aim of the study to investigate the gait dynamic improvements following TKR surgery by compare the dynamic parameter pre-operative and post-operative and then comparing the results with the normal gait parameters. The gait analysis was performed on five patients before and after they underwent unilateral TKR surgery. After three months from the total knee replacement there was a remarked increase in the function and decrease in pain. The varus and valgus malalignment will be return to normal alignment after operation, which is one of the main goals of the TKR. Post-operative cadence is higher than pre-operative for four patients, post-operative speed is faster than pre-operative for four patients and post-operative stride length is larger than pre-operative for four patients. The patients continue to walk with significant gait abnormalities by examining the kinetics and the kinematics of the operated limb, the results show the knee function not fully restored three months after unilateraL TKR surgery.*

Keywords- *Total knee replacement, Gait analysis, OKS, Time-distance parameters measurement, dynamic gait parameters.*

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1. Introduction

Gait analysis is the systematic study of the human walking, which is useful for description normal and pathological locomotion patterns, and suggestion of physiotherapy as well as calculation of the results of such therapy. The walking process combines complex interactions between bones, muscles, ligaments, tendons and the neurons in the human body. Different parts of the patients attempting to compensate for the problem as a result they present a number of the gait irregullatories. Two terms are commonly used in the gait analysis kinetics and the kinematics. The kinetics describes the motion in term of the forces, moments and powers but without any details about the orientation or position of the objects involved, the kinetics measurements are done by the force platform device which is used for measure ground reaction forces and moments. The kinematics describes the motion in terms of angles, velocities, positions and accelerations, various techniques are used for the kinematics measurements. The available one is the video motion by using single camera and markers placed on skin surfaces in the location accurately represents the action of underlying joints. The joints (hip, knee and ankle) forces, powers, angles and moments are then obtained by the inverse dynamics to the data collection from the camera in combined with the force platform and anthropometric data from tables. The knee joint is the largest joint in the human body, thigh and lower leg bones are joined by a complex array of muscles, ligaments, tendons and cartilage, the knee structure permits the bearing of tremendous loads and the mobility required for the locomotors activities. The tibiofemoral joint during daily activities is loaded in both shear and compression. During the stance phase of the gait the compression is slightly greater than three times body weight, increasing approximately to up to four times body weight during stair climbing [1]. When the pain is significant and disable and the joint losses its stability due to the severe arthritis then the TKR is indicated to restore joint stability (The natural or replaced joint range of motion is interconnected to its stability, the more mobile joint the less stable and depending on the surrounding soft tissue for stability) and relieve the pain and restore the alignment of the lower extremity [2]. The age-related and the most common type of arthritis is the osteoarthritis (OA), the majority of affected patients are above 50 years nevertheless younger people may also suffer from the disease, it's caused by the prolonged tear and wear of the joint leading to the inflammation, breakdown and loss of cartilage. Also an inflammatory arthritis is the rheumatoid

(RA). It's caused by the inflammation of the synovial lining the knee joint. The stiffness and soreness of the knee occur when the inflammation becomes chronic and will damage the cartilage and later damage bones ending. Post Traumatic Arthritis: it's caused by severe knee injury when the ligaments around the knee is tear or cartilage is damage or the bones is break result in mechanical dysfunction. Total knee replacement (TKR) is a surgical procedure that performs to replace the weight-bearing surfaces, the technical goals of the TKR joint are to restore function, mobility and the biomechanical goals are to restore normal limb alignment for the patients with osteoarthritis, rheumatoid arthritis, post trauma arthritis and other disease by correcting knee deformities [3]. Numerous and long-term gait analysis (kinetic and kinematic) studies have been made for the lower limb joints [4], made a complete functional comparison by isotonic muscle testing and gait analysis between sixteen patients with total knee replacement (TKR) and control subjects [5], measured the gait parameters in patients with osteoarthritis (OA) before and after TKR [6], evaluated gait kinetic, kinematic and residual muscle function abnormalities after TKR [7], three dimensional analysis investigated whether an abnormal flexor moment pattern at twelve months post-TKR could be predicted assessed four months post-surgery and before surgery by using biomechanical gait measures and there are a number of studies of the relationship between the changes in the gait parameters for the patients with total knee replacement.

2. Methods

The gait analysis was performed on five patients before and 3 months after they underwent unilateral total knee replacement (TKR) surgery at the biomedical engineering department/Al-Nahrain University. Two dimensional sagittal plane measurements (angles, powers, forces and moments) is made by using one digital video camera with seven passive markers placed on an anatomical position as shown in Figure 1, with force platform which contains two plates mounted on rigid, flat surfaces within (6000×1220×106) mm wooden walkway. The force platform used to measure forces and moments and 2D motion analysis is used to measure x, y coordinate center of hip, knee and ankle joints. The data of the force platform and the camera are transferred to the computer system through USB connection. The force plate data analyzed by the Bioanalysis software and the camera data digitized by skillspectro. The kinetics data are combined with the kinematics data by using MATLAB to give forces, moments, powers and angles for the hip, knee and ankle joints. The gait of the patients was performed before and 3 months post-operative in five trials at free speed and barefoot along (6m) walkway where the patient's foot landed on the center of the force plate. The post-operative results were compared with pre-operative and normal results of control group from literature [8].

3. Patients and Results

Five patient three females and two males referring to the Biomedical Engineering Department/ Al-Nahrain University were included in the study. Patient's weight and height were taken from a scale. Patient's characteristics are summarized in Table 1. All patients must have the ability to walk on a six meters walkway without any aid of cane with no severe arthritic at other joints of the lower limbs, and no systematic pathologic. The study group with an average age of 57.8 years (range, 49-70 years), average height of 1.589 m (range, 1.47-1.675 m) and average weight of 84.1 kg (range, 74.800-87.500 kg). All patients underwent a unilateral TKR by the same surgeon and the gait analysis was evaluated before and after 3 months TKR. All patients participated in pre-operative and post-operative test (the first experimental session was scheduled within 14 days prior to TKR surgery and the second experimental session was carried out for them after three months post-TKR surgery). Four patients received a left unilateral TKR and one of them received a right unilateral TKR surgery.

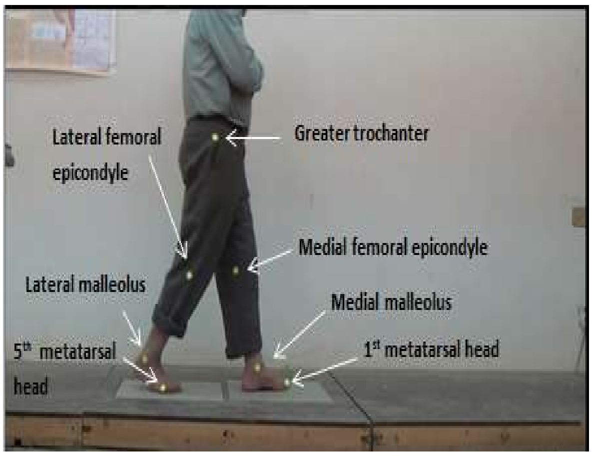

Figure 1: markers location

Table 1: Patient's characteristic

Case no.	1	2	3	4	5
Age	50	60	60	70	49
Gender	Female	Female	Male	Male	Female
BMI (kg)	74.800	86.200	85.500	86.500	87.500
Height (m)	1.59	1.54	1.67	1.675	1.47
Diagnosis	RA	Primary OA	Secondary OA (post traumatic)	Secondary OA (post traumatic)	Primary OA
Abnormal side	Left	Left	Right	Left	Left
Varus/Valgus	Valgus	Varus	Varus	Varus	Varus

I. Oxford Knee Score (OKS)

The score is 12-items patient reported designed and developed to measure the outcome after TKR. The pre-operative and post-operative scores change give an indication about the improvement in function and pain reduction after the replacement. The average improvement in the pain component subscale of 67.124 points (range, 24.99-100 points) and in the functional component subscale of 53 points (range, 5-90 points). The OKS (functional and pain component pre-TKR) is (0) for the patient number 3 because he did not have the ability to walk. During each experimental session, each patient completed a self-administrated questionnaire of OKS as reported in Table 2.

II. Time-distance parameters measurement:

Data obtained from the time and distance measurements for pre-operative and three months TKR post-operative are reported in Table 3. All patients for both pre-operative and post-operative as compared with normal [8] walked with a significant slower speed, lower cadence and shorter stride length. Post-operative cadence is higher than pre-operative for four patients, post-operative speed is faster than pre-operative for four patients and post-operative stride length is larger than pre-operative for four patients.

Table 2: Patient's Oxford Knee Score

Case no.		1	2	3	4	5
Functional component score	Pre-surgery (points)	25	15	0	55	25
	Post-surgery (points)	80	75	90	60	80
	Improvements (points)	55	60	90	5	55
Pain component score	Pre-surgery (points)	7.14	3.57	0	57.12	17.85
	Post-surgery (points)	92.82	71.4	100	82.11	24.99
	Improvements (points)	85.68	67.83	100	24.99	57.12

Table 3: Patient's time-distance parameters

Case no.		1	2	3	4	5
Cadence (steps/min)	Pre-TKR)	76.433	87.591	78.431	96.774	106.194
	Post-TKR	89.552	89.552	102.564	75	105.263
	Normal range	115-120	115-120	110-115	110-115	115-120
Speed (m/s)	Pre-TKR	0.695	0.773	0.656	1.003	0.86
	Post-TKR	0.92	0.924	1.055	0.646	0.929
	Normal range	1.2-1.5	1.2-1.5	1.3-1.6	1.3-1.6	1.2-1.5
Stride length (m)	Pre-TKR	1.091	1.06	1.004	1.241	0.972
	Post-TKR	1.233	1.238	1.234	1.033	1.059
	Normal range	1.3-1.5	1.3-1.5	1.4-1.6	1.4-1.6	1.3-1.5

III. Sagittal plane angles

Hip, knee and ankle angles are presented in Figure 2 and Table 4.

1. Hip joint angle

The post-TKR as compared with normal group:

- Maximum Flexion in stance phase from (0%-62%) of the gait cycle and during swing phase (62%-100%) of the gait cycle for patients (1, 3 and 4) was within normal
- The maximum hip extension at terminal stance (35%-55%) of the gait cycle for three months post-operative was greater than normal for patients (1, 2). For pre-TKR as compared with post-TKR:

1. Maximum flexion in stance phase from (0%-62%) of the gait cycle and during swing phase (62%-100%) of the gait cycle for patients (2, 3) walked with a greater hip flexion as compared with pre-TKR.
2. The maximum hip extension at terminal stance

(35%-55%) of the gait cycle for patients (1, 3, 4) for post-TKR walked with a decreased hip extension as compared with pre-TKR.

So the hip joint after TKR exhibits increase range of motion than normal and less range of motion than pre-operative because whole leg must be accelerated forward as a one unit, which increased the demands on hip flexors in a compensatory movement because the patient was unable to flex his knee and there was no ankle planter flexion.

2. Knee joint angle*:* The post-TKR as compared with normal group:

- Maximum knee flexion was lower than normal for all patients.
- The maximum knee extension in the stance phase (0%-60%) of the gait cycle was higher than normal except the patients (1 and 4) the extension was disappeared.

For pre-TKR as compared with post-TKR (V1/V2)

1. Maximum knee flexion for patients (1, 3, 4) walked with a greater knee flexion as compared with pre-TKR.
2. The maximum knee extension for patients (1, 2) for post-TKR walked with a greater knee extension as compared with pre-TKR.
3. Ankle joint angle*:* The post-TKR as compared with normal group (V2/C):

- Maximum ankle dorsiflexion in the stance phase (0-60) % of the gait cycle for patients (1, 2, 4) was greater than normal.
- Maximum ankle dorsiflexion in the swing phase (60-100) % of the gait cycle for patients (1, 2) was higher than normal and for the patients (3, 4) was disappeared.
- Maximum ankle planter flexion in the swing phase (60-100) % was disappeared which is called foot drop that is as a result of the weakness of the planter flexion muscles.

For pre-TKR as compared with post-TKR there is no a significant improvements.

IV. Reaction force: hip, knee and ankle reaction forces are presented in Figure 3 and Table 5.

1. Hip reaction force*:* Hip reaction forces had two distinct peaks. The first peak, or loading peak, represents the load acceptance of weight onto the limb. The second peak, or push off peak, represents the vertical component of the push onto the opposite limb. There is no a significant improvement in the reaction force after three months of TKR as compared with the pre-operative. Both results of pre-operative and post-operative were lower than normal.
2. Knee reaction force*:* There is a slight improvement in the reaction force after three months of TKR as compared with the pre-operative. Both results of pre-operative and post-operative were lower than normal.
3. Ankle reaction force*:* There is a small improvement in the reaction force after three months of TKR as compared with the pre-operative. Both results of pre-operative and post-operative were lower than normal.

Reduction in joint's reaction forces means abductor muscles weakness.

Table 4: mean (±SD) of hip, knee and ankle joints angles for normal subject, three months post-operative and pre-operative during gait cycle.

	Normal	Post-operation	Pre-operation
Maximum hip flexion° (0-100)%	20.506 ±5.045	26.4 ±9.4	27.7 ±7.084
Maximum hip extension° (0-100)%	-11.533 ±2.832	-14.4 ±5.16	-15.477 ±11.545
Maximum knee flexion° (0-100)%	51.210 ±8.892	34.1 ±3.216	21.213 ±13.313
Maximum knee extension° (20-60)%	7.839 ±3.205	9.8 ±9.516	11.601 ±11.192
Maximum ankle dorsiflexion° (0-60)%	11.175 ±3.2995	18.4 ±7.099	12,8 ±2.977
Maximum ankle dorsiflexion° (60-100)%	8.165 ±3.241	9.3 ±9.042	8.9 ±6.445
Maximum ankle planter flexion° (60-100)%	-14.820 ±5.410	4 ±7.931	5 ±6.058

Table 5: mean (±SD) of hip, knee and ankle joints reaction forces (N/Body weight) for normal subject, three months post-operative and pre-operative during gait cycle.

	Normal	Post-operation	Pre-operation
Hip force	3.159 ±0.147	1.728 ±0.088	1.665 ±0.069
Knee force	3.538 ±0.125	1.956 ±0.075	1.884 ±0.06
Ankle force	3.738 ±0.178	2.04 ±0.105	1.968 ±0.065

V. Moments

Hip, knee and ankle moments are presented in Figure 4 and Table 6.

1. Hip moment*:* during the loading response and mid stance the first maximum hip flexion for both post-operative and pre-operative was higher than normal. During the gait cycle the maximum hip extension was disappear to reduce hip compressive load in the affected limb. In addition, during terminal swing the second maximum hip flexion was disappeared for most patients
2. Knee moment*:* During the mid-stance the first maximum knee, flexion for post-operative was within normal range and there is a significant improvement as compared with pre-operative

result. And during the swing phase the maximum knee extension and second maximum knee flexion was disappeared

3. The maximum ankle moment for most patients after operation was better than the pre-operative results and the minimum ankle moment were disappeared.

VI. Powers: hip, knee and ankle powers are presented in Figure 5 and Table 7

1. Hip power*:* the first maximum hip power generation for both the pre-operative and post-operative results was higher than normal for most patients during the early stance.

Moreover, during the terminal stance the maximum hip power absorption was disappeared in most patients. In addition, during initial swing the post-operative second maximum hip power generation was better than the pre-operative was and lower than normal.

2. Knee powers: the first maximum knee power absorption for both the pre-operative and post-operative results were disappearing during the early stance for most patients. After foot flat the maximum knee power generation was disappear. During late stance and early swing the second maximum power absorption was disappear and the third maximum knee absorption for post – TKR was greater than pre-TKR

3. Ankle powers: During the periods of the stance of the foot flat to about (40%) of the gait cycle the maximum power absorption for both post and pre-operative was disappear for most patients and during the late stance (40-60) % of the gait cycle the maximum power generation was lower than normal. Moreover, during the late swing and initial contact the second maximum ankle power generation for pre-operative was better than pre-operative for two patients.

Table 6: mean (±SD) hip, knee and ankle joints moments (N.m/kg) for normal subjects, three months post-operative and pre-operative during gait cycle.

	Normal	**Post-operation**	**Pre-operation**
1st max. hip flexion moment (0-30)%	0.467±0.181	1.21±0.569	1.078±0.348
2nd max. hip flexion moment (80-100)%	0.164±0.036	0.045±0.056	disappear
Max. hip extension moment (0-100)%	-1.181±0.341	-0.102±0.154	-0.16±0.153
1st max. knee flexion moment ((0-30)%	0.483±0.170	0.334±0.117	0.298±0.137
Max. knee extension moment (30-70)%	-0.610±0.320	-0.042±0.079	-0.02±0.024
2nd max. knee flexion moment (60-100)%	0.606±0.277	0.034±0.032	0.018±0.035
Max.ankle moment (0-100)%	1.269±0.146	0.91±0.315	0.922±0.198
Min. ankle moment (0-100)%	-0.065±0.004	-0.05±0.07	0.014±0.005

Table 7: mean (±SD) of hip, knee and ankle joints powers (W/kg) for normal subject, three months post-operation and pre-operation during gait cycle.

	Normal	Post-operation	Pre-operation
1st max. hip power generation (0-25)%	0.462±0.262	1.108±0.487	1.156±0.393
Max. hip power absorption (25-60)%	-0.548±0.154	0.49±0.783	0.43±0.593
2nd max. hip power generation (60-100)%	0.685±0.205	0.12±0.04	0.042±0.08
1st max. knee power absorption (0-20)%	-0.184±0.048	-0.02±0.098	-0.06±0.12
Max. knee power generation (20-40)%	0.137±0.064	-0.04±0.082	-0.04±0.08
2nd max. knee power absorption (40-70)%	-1.697±0.680	-0.05±0.1	-0.08±0.136
3rd max. knee power absorption (70-100)%	-0.209±0.133	-0.2±0.055	-0.12±0.112
1st max. ankle power generation (25-70)%	4.582±0.739	0.958±0.616	0.76±0.48
Max. ankle power absorption (0-25)%	-0.136±0.118	-0.08±0.075	-0.02±0.039
2nd max. ankle power generation (70-100)%	0.283±0.168	0.06±0.381	0.02±0.04

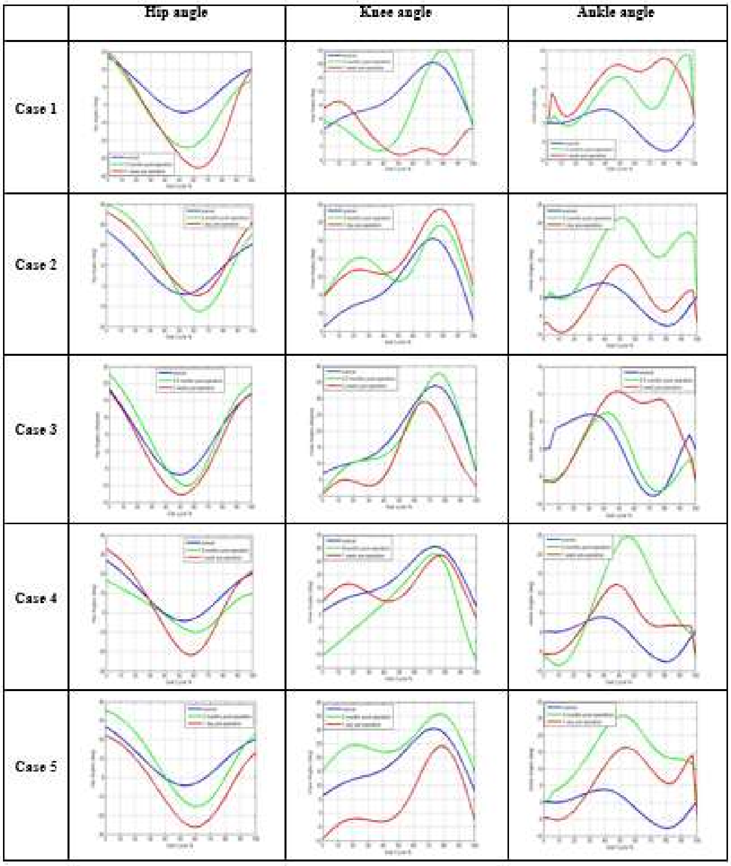

Figure 2: Sagittal plane hip, knee and ankle angles during gait cycle for five patient.

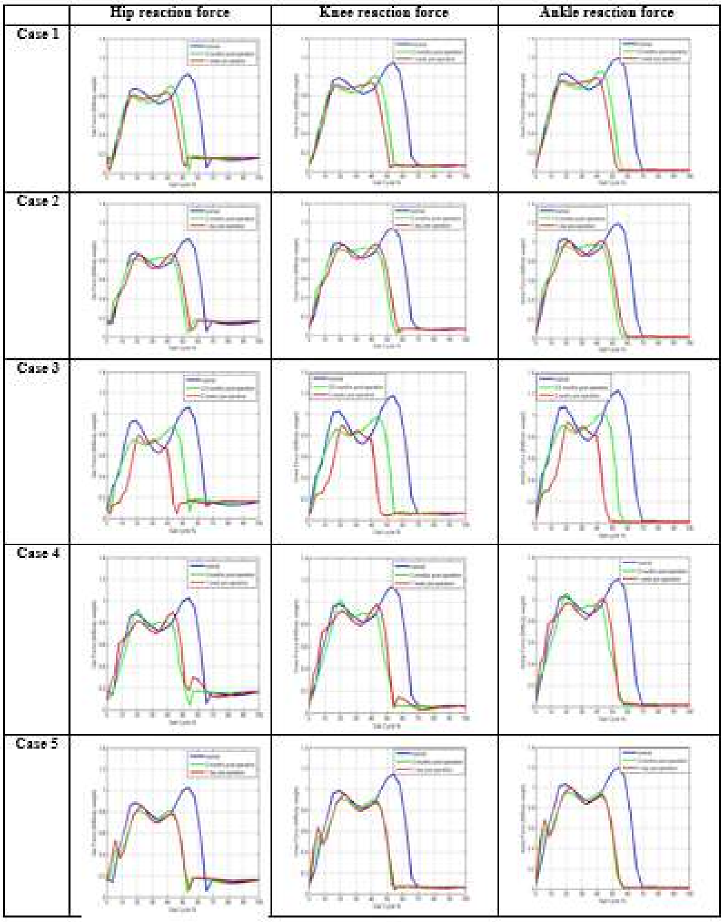

Figure 3: Hip, knee and ankle reaction forces during gait cycle for five patient.

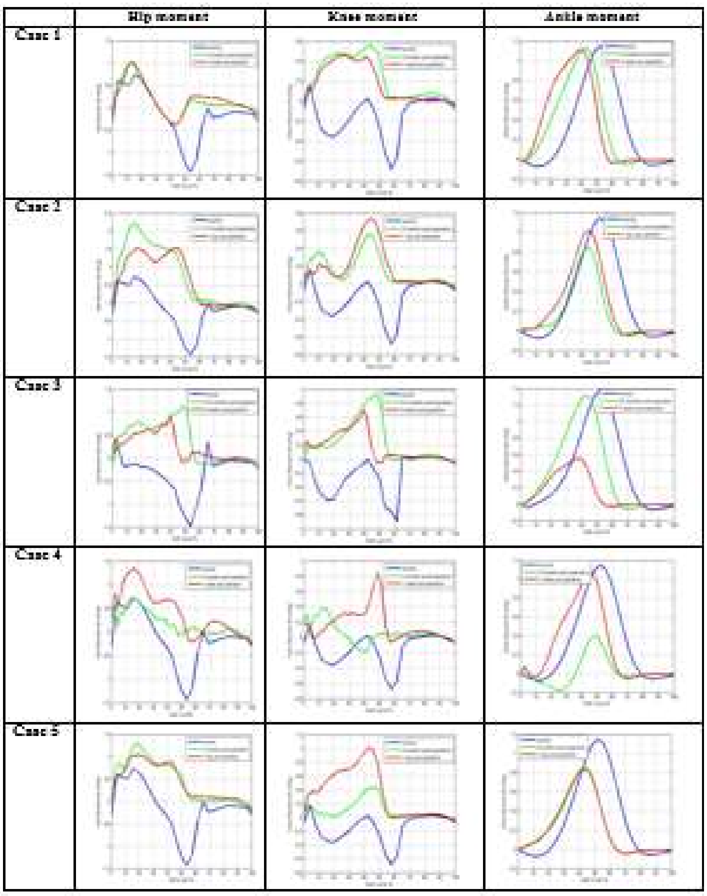

Figure 4: Hip, knee and ankle moments during gait cycle for five patient.

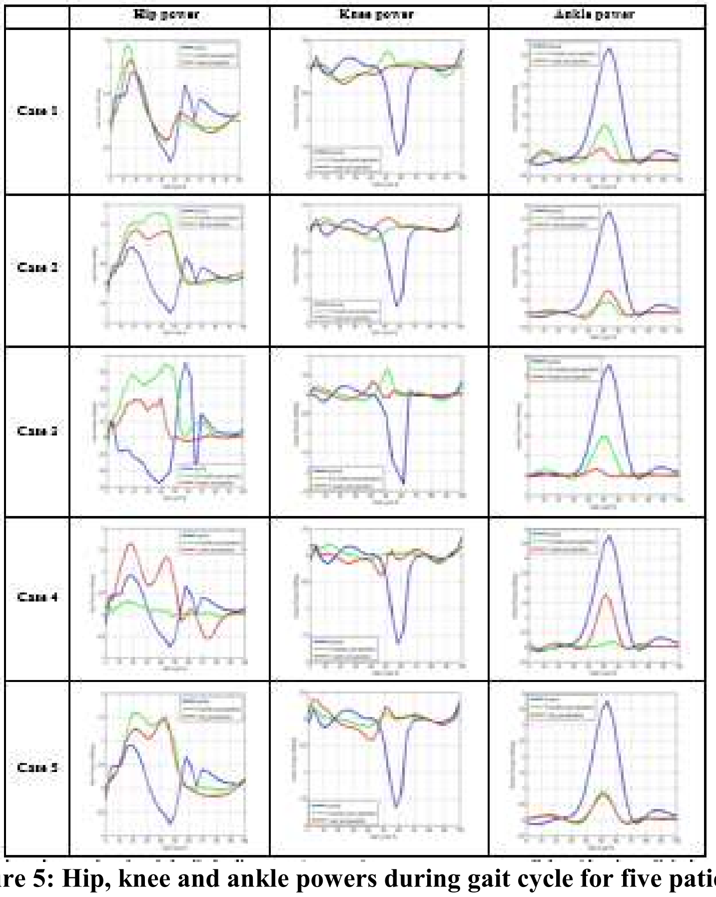

Figure 5: Hip, knee and ankle powers during gait cycle for five patient.

4. Discussion

The knee pain after three months unilateral TKR have been reduced and the limb alignment (varus and valgus) was restored for the all patients, which are the main goals of the TKR surgery. The pain component subscale and the function component subscale have a significant improvement which is mean a decrease in pain and increase in function. The time-distance parameters measurements (cadence, speed and stride length) improved after three months unilateral TKR surgery, but it's still lower than normal range. The dynamic gait parameters (angles, forces, powers and moments) improvements not parallel with the clinical improvements because the patients continue to walk with a significant gait abnormalities by examining the kinetics and the kinematics of the operated limb. The results show the knee function not fully restored three months after TKR surgery. It's possible that the non-operated limb is used more by the patient in order to protect the new prosthesis and as a result of osteoarthritis there is a limitation in the proprioception (awareness in the ability to estimate the force generated within the joint, joint position sense and joint movement) [9]. The patients subjected to TKR surgery may have disturbed some of muscles and ligaments that responsible for applying forces to the knee joint. A major limitation of this study is the finding the patient who are able to walk on six meters force platform, the difference of the body mass index (BMI) between normal group and the patients group the patients BMI was higher than normal and the high BMI can influence the trajectories of the markers and introduce some artifact movement which can affect the final gait pattern results [10]. Previous studies reported an abnormal gait patterns at 12-18 months.

5. Conclusion

1. Gait analysis with a simple system is useful in documenting gait abnormalities before and after TKR surgery.
2. Gait analysis is useful in suggestion of physiotherapy and as well as calculation of the result of such therapy.
3. The three months after unilateral TKR surgery improvements of OKS (pain component subscale and function component subscale) reflect the effectiveness of the surgery in improving the quality of life.
4.Despite some of improvements in time-distance parameters, it was observed that the knee joint function is not fully restored to normal in term of time-distance parameters (cadence, speed and stride length). These improvements may indicate enhanced locomotors ability after unilateral TKR surgery.
5. Despite some improvements in the dynamic gait parameters (angles, forces, powers and moments), the patients continue to walk with a significant gait abnormalities, the gait pattern abnormalities reflect the reduced load on the new knee prosthesis so the patients should advised that three months post-operative is a critical periods and the rehabilitation process is long and lasting more than three months. The gait abnormalities at the hip and the ankle joints may be a compensatory response to facilitate forward momentum and allow sufficient power generation at the knee joint.

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