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**Manuscript Title**

Advanced functional biomechanical analysis of medial rotation knee arthroplasty

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**Advanced Functional Biomechanical Analysis of Medial Rotation Knee Arthroplasty**

**Abstract**

Objective: The Medacta GMK-Sphere total knee arthroplasty (TKA) is designed to mimic the movements and stability of a natural knee for optimal post-operative function and mobility. This study aimed to quantify the early functional outcome of patients with this implant.

Design: Patients due to undergo TKA to treat end-stage osteoarthritis were recruited into this study. Functional tests of knee range of motion (ROM), strength, and gait kinematics were carried out pre-operatively and 1-year post-operatively at routine clinics. Motion capture technology and a force transducer were used to collect all data. Normality tests were completed on all data sets to confirm normal distribution of the data, then paired t-tests were used to statistically compare the results. The level of significance was set as $α$ = 0.05.

 Results: 63 patients underwent pre-operative assessments; of which 30 returned 1-year post-operatively and consented to have follow-up testing. The operative knee was found to have poorer function than the contralateral knee pre-operatively (p < 0.05). Post-operatively, knee ROM significantly improved on the operative side to a mean of 116.1±19.0. Gait kinematics also improved, especially in the frontal plane, but some abnormal traits remained in the sagittal plane. Knee strength decreased post-operatively.

Conclusions: The Medacta GMK-Sphere TKA improves knee range of motion sufficiently within the first postoperative year to allow patients to carry out most activities of daily living (>110° knee flexion), but continued poor knee strength may limit their abilities to complete tasks which are more biomechanically demanding than walking.

**Keywords:** Total knee arthroplasty; functional outcome; biomechanics; range of motion; strength; gait

**Introduction**

Total knee arthroplasty (TKA) was first introduced to relieve knee pain caused primarily by osteoarthritis (OA) in elderly populations[1]. As a consequence, traditional implants were not designed to allow patients to achieve high levels of knee function. Over recent years however, the patient demographic has changed, and people now requiring TKA are younger and/or more active than before. Current patients therefore expect to be able to carry out more biomechanically demanding tasks post-operatively [2]. Thus, the need for implants that allow patients to achieve high range of motion (ROM) at the knee with stability and improved function is increasing.

Most common modern-day implants rely on the congruency between the femoral and tibial parts to provide knee stability in the absence of one or both cruciate ligaments. However, many patients exhibit instability of the knee with these devices during use[4]. The Medacta® GMK-Sphere (Medacta International: Castel S. Pietro, Switzerland) implant has been designed to specifically address this issue, by altering the way in which the implant is stabilised to mimic the anatomical actions of a healthy knee joint.

To replicate the articulation movements of a healthy knee, the medial compartment of the Medacta GMK-Sphere implant was constrained with a spherical bearing, while flat lateral tibial baseplate and lateral femoral components allow rotation and the screw home mechanism (Fig.1). Additional medial femoral constraint is given by a high antero-medial polyethylene tibial baseplate (Fig.1). Together, these create a medial ‘ball-and-socket’ effect, limiting the sliding movement of this condyle, as has been shown to occur in the natural knee[4].

In addition to adapting the articulating surfaces, the patellar groove has been shifted into an anatomical location (2mm lateral to midline) and the lateral femoral compartment enlarged anteriorly to better replicate patellar tracking and prevent lateral patellar dislocation (Fig.2). The components of the implant are also available in a wide variety of sizes to allow for improved implant fitting.

The Medacta GMK-Sphere TKA claims to improve post-operative knee function by providing patients with better knee motion and stability compared to standard implants. However, the functional outcome of this novel implant has not yet been independently investigated. The aim of this study was to biomechanically quantify the early functional outcome of this novel implant.

**Materials and Methods**

Patients who presented to elective orthopaedic clinics with clinical and radiographic symptoms of end-stage OA meriting TKA were recruited into this study. Patients were excluded if they presented with inflammatory arthropathy, required bone augmentation, or had ligament incompetence or a valgus deformity >5°. In cases where patients suffered from bilateral knee OA, the worst affected knee was chosen for TKA.

This study was approved by the local NHS research ethics committee in 2015 (REC reference: 15/SS/0058; IRAS ID: 177817). The patients gave written and verbal consent to participate.

All surgical procedures were performed by one consultant orthopaedic surgeon. The surgical technique involved a medial parapatellar approach. Both cruciate ligaments are excised. The implant is deep-dish medial and a flat lateral design with no central post. Anterior-posterior stability is inherent to the design of the implant. The TKA was implanted using a tourniquet for cementing.

Functional assessments were completed during routine appointments both pre-operatively and one-year post-operatively. Pre-operative assessments were completed within six weeks of the planned surgery at routine pre-admission clinics. Post-operative assessments were carried out as near as possible to the date of surgery (within a week) one year later. Patients were free to rearrange their routine appointment for earlier or later due to other commitments, however.

The assessments were carried out using a motion-capture system which consisted of a treadmill (Motekforce Link: Amsterdam, The Netherlands), 8 Vicon Bonita infrared cameras (Vicon Motion Systems: Oxford, UK) and a force transducer (1000N, White Ltd., Oxford, UK). Specialised software was used to control the treadmill and track the patients’ movements, and a bespoke model was used to calculate all biomechanical data from clusters of reflective markers (D-Flow, Motekforce Link: Amsterdam, The Netherlands)[5].

Three separate tests were completed during each visit. The first objectively measured active and passive knee ROM, the second quantified the isometric strength of the knee flexors and extensors at 90 degrees of knee flexion, and the third assessed knee kinematics during a walking task. Kinematics for gait and ROM assessments were calculated as per International Society of Biomechanics recommendations[6,7]. Gravity corrected flexor and extensor torques were calculated from the force data output from the transducer.

Before beginning the assessments, 7 clusters of markers were firmly secured onto the pelvis, legs and feet of each patient using elasticated Velcro straps. Twenty anatomical landmarks were then calibrated by the researcher using an instrumented pointer to generate the biomechanical model from which all variables were calculated [5]. Once complete, patients were asked to lie in a supine position on a plinth with both hips in a neutral position (near 0° flexion). They were then instructed to flex and extend the knee to the best of their ability by sliding their foot towards and then away from their rear (simultaneously flexing and extending the hip) to assess active knee ROM. Passive ROM was also assessed. For passive assessment of knee ROM, the researcher asked the patient to relax their leg enabling the researcher to flex and extend the knee to the best of its ability by sliding the foot towards and then away from their rear.

The plinth was then removed and replaced with a chair. Patients were instructed to sit on the chair and a strap which was attached on one end to the force transducer was fastened around one ankle. The knee was set at 90° then the patient was asked to exert as much force as possible against the strap to measure isometric strength of the extensors (quadriceps). The chair was then reversed and the test repeated to measure isometric strength of the flexors (hamstrings). Torques were calculated for each test by combining the force data and the lever arm of the strap around the knee.

Three attempts were completed for each of the above-mentioned tests, but only the maximum ROM and torques achieved were included in the analyses.

Finally, the patients walked on the treadmill for 2 minutes. Treadmill belt speed was driven by the position of the patient’s pelvis on the treadmill; belt speed increased as the patient walked faster (approaching the front of the treadmill), and belt speed decreased as the patient slowed down (approaching the rear of the treadmill). The patients were instructed to walk at a speed that they would consider their normal walking speed on level ground. This treadmill and protocol was chosen as an attempt to replicate each patient’s natural walking speed. Mean sagittal, frontal and transverse plane kinematics of the knee recorded over 50 consecutive cycles were used in the data analyses. Gait kinematics of other joints were not examined for the purposes of this study.

To ensure reproducibility of the biomechanical model, the same researcher performed all anatomical landmark calibrations with the same instrumented pointer. The orientation of the pointer when calibrating anatomical landmarks was also kept consistent by the researcher, so as not to introduce variability into the results through inconsistent calibration [8]. The researcher also completed all assessments in the same order (as explained above) with each patient pre- and post-operatively.

Phases and events of the gait cycle were defined from heel and toe positions during gait. An algorithm written in MATLAB (ver. R2014a: Mathworkds Natick, MA) was used to calculate these events from the trajectory data. Statistical analyses of the data were carried out in Minitab software (ver. 16: Minitab Inc., State College, PA, USA). Normality tests were carried out on all data sets to confirm that the data were normally distributed then paired t-tests were used to statistically compare the results. The level of significance was set as $α$ = 0.05.

**Results**

Sixty-three patients were recruited into this study (30 males/33 females). The patients had a mean age of 71.2±8.4 years, a mean mass of 83.3±17.1kg, a mean height of 1.65±0.11m and a mean BMI of 30.5±4.7kg/m2. A left TKA was carried out on 39 patients and a right TKA on 24. On average, the pre-operative assessments were carried out 23 days pre-operatively and the post-operative assessments completed 290 days post-operatively (9.5 months). Some patients recruited into this study suffered from bilateral knee OA; 5 of whom underwent a TKA on the second knee within one year of the first TKA. No other conditions which may have influenced the function of their knee (neurological or otherwise) were reported. All (n=63) but three participants (n=60) consented to pre-operative biomechanical assessment. Of the 63 participants 30 returned during the study period and gave consent for postoperative biomechanical assessment; however, three of these patients had not undergone the preoperative assessments. Thus statistical analyses of differences between pre- and post-operative knee function were carried out on the data from 27 patients whose full datasets were available to us.

Pre-operative knee ROM was significantly greater in the contralateral knee than the operative knee: Active ROM p = 0.004, Passive ROM p < 0.0001 (Table 1). One year post-TKA, passive and active ROM of both knees improved beyond baseline levels (Table 1). These improvements were found to be statistically significant in the operative knee of the 27 participants who attended both appointments: Active ROM p < 0.0001, Passive ROM p = 0.004. ROM of the operative knee had improved such that there were no statistical differences between passive (p = 0.661) and active (p = 0.312) ROM of the operated knee when compared to the contralateral knee at one-year (Table 1).

Maximum knee strength was greater in the contralateral knee than the operative knee pre-operatively, especially during flexion (Table 2). Differences were statistically significant (Table 2; Flexors: p = 0.026 & Extensors: p = 0.039). Maximum flexor strength was statistically greater than maximum extensor strength in both knees pre-operatively (Contralateral Knee: p = 0.004 & Operative Knee: p <0.0001). One year post-operatively, the strength of both knees was lower than previously recorded (Table 2; Flexors: p = 0.941; Extensors: p = 0.803). There were no differences between the strength of the flexors and extensors in either the operated or contralateral knee one year post-operatively (Table 2; Flexors: p = 0.346 & Extensors: p = 0.413). Statistical analyses on data from 27 patients showed that the reduction in operative knee flexor strength between pre- and post-operative was significant (p = 0.017). Reductions in operative knee extensor strength were not significant, however (p = 0.229).

Pre-operatively the patients had an average walking speed of 0.34±0.10m/s (n = 63). This improved to 0.41±0.22m/s post-operatively (n = 30). In the 27 patients who attended both appointments, average walking speed significantly improved from 0.32±0.07m/s to 0.52±0.27m/s (p = 0.001).

During gait, patients made initial contact with the treadmill with the knee flexed by approximately 20° pre-operatively (Figure 3A). The contralateral knee displayed a higher degree of flexion at this stage of the gait cycle, and differences between knees were not significant (Table 3 & Table 4; p = 0.241). Towards the end of the stance phase, the degree of flexion recorded in the operative knee was statistically greater than in the contralateral knee (Table 4; p = 0.013), but the contralateral knee achieved a greater maximal knee flexion angle during the swing phase. These differences in swing did not reach statistical significance (Table 4; p = 0.836). Rapid extension of both knees occurred during terminal swing in preparation for the next step. Neither knee became fully extended towards the end of the gait cycle again indicative of a flexed knee gait.

One year post-operatively, the patients continued to show signs of abnormal gait at initial contact (Figure 3 & Table 3). This persisted into the loading response and mid-stance events of the gait cycle. However, the maximum knee flexion angle achieved was greater than previously recorded in both knees. Statistical analyses showed that there were no longer any differences between knees during stance phase. The maximum angle achieved at the knee during swing was statistically greater in the operative knee than the contralateral knee (Table 3 & Table 4; p < 0.0001). Differences between pre- and post-operative sagittal plane kinematics were statistically significant in each gait event assessed (Table 5; p < 0.05).

Little frontal plane rotation was observed during gait pre-operatively. The contralateral knee remained abducted by approximately 2° throughout stance and adducted during swing (Figure 3B). In contrast, the arthritic knee remained in adduction throughout the gait cycle (Figure 3B). Statistical analyses of the data showed that knee kinematics only differed to a significant extent during terminal stance (Table 3 & Table 4; p = 0.037).

One year following surgery, frontal plane rotation of the operative knee better reflected the contralateral knee, which displayed similar kinematic trends to those observed during baseline assessments (Figure 3B). There were no longer any statistical differences between frontal plane kinematics of either knee (Table 4; p > 0.05). Differences between pre- and post-operative frontal plane kinematics were statistically significant in all gait events other than mid-swing (Table 5; p < 0.05).

The knees exhibited very little rotation in the transverse plane during stance pre-operatively. Internal rotation was recorded during swing; more notably so in the contralateral knee. There were no differences between transverse plane kinematics of the operated and contralateral knees during key events of the gait cycle (Table 3 & Table 4; p > 0.05). One year post-operatively, transverse plane kinematic trends remained similar to baseline data, but both knees exhibited greater ROM during the gait cycle than at baseline (Figure 3C). There continued to be no differences between knees during certain events of the gait cycle (Table 4; p > 0.05). Statistical analyses on pre- and post-operative data confirmed that there were no significant differences in transverse plane kinematics over time (Table 5; p > 0.05).

**Discussion**

The Medacta GMK-Sphere TKA is designed to provide patients with a better functioning and stable implant than traditional design implants. This study aimed to quantify the functional outcome of this implant to determine whether any early functional benefits were encountered.

Pre-operatively, the patient cohort exhibited mean joint ROM that is typical of end-stage OA [9-12]. ROM in the contralateral knee was also limited, but not to the same extent. Many patients involved in this trial exhibited symptoms of OA in both knees, potentially explaining why high flexion knee ROM could not be achieved in either knee. Active knee flexion of 110° is required to complete most activities of daily living [13]. As the average patient could not achieve this pre-operatively, it can be inferred that certain activities of daily living would have been difficult or impossible for many patients at this stage [13,14].

One year post-operatively, ROM of the operative knee had significantly improved beyond baseline levels (Table 1). According to the criteria of Meneghihi and colleagues, the average maximum flexion achieved in both knees at 1-year can be considered as normal [14], and the mean ROM was consistent with other published studies [12, 15-19], where active knee ROM was measured at least 12 months post-operatively. Not all studies state which implant was used in the research, however similar results to the GMK-Sphere have been reported in the following implants: Stryker’s Kinemax – 109.4±11.8° [12], Ceraver’s Ceragyr - 107.9±12.5° [15], Smith and Nephew’s Genesis II – 109.0±13.0 [16] and 117.0±15.0 [18], and Zimmer’s NexGen – 117.5±1.7° [19]. Our result is especially encouraging, when considering the average follow-up time in this study was 9.5 months compared to a minimum of 12 months in these other studies. Our data therefore suggest that the Medacta GMK-Sphere implant is successful at restoring knee ROM to functionally acceptable levels (>110° flexion) within the first post-operative year.

On average, both knees showed statistically greater muscular strength in the flexors of the joint pre-operatively (Table 2). This finding is not uncommon in patients suffering from knee OA, as the quadriceps muscles responsible for extending the knee are weakened by the disease [20-22]. Rossi et al., reported a mean maximum extensor strength of 43.1±17.3Nm in their patients [23], and Samuel & Rowe (2009) reported average flexor and extensor strengths of 47.7±11.3Nm and 55.3±13.3Nm, respectively in similar-aged older adults [24]. The results recorded in this study were consistent in magnitude to those presented in these papers.

One year post-operatively, the maximum strength of both muscle groups decreased bilaterally by such an extent that the results were poorer than pre-operatively (Table 2). The poorest results were recorded in the contralateral knee. A decrease in strength in both knees following TKA was also reported by Yoshida and colleagues in 2012 [25]. In our study, this reduction in strength may be explained by the fact that a significant number of patients had developed further symptoms of OA in other joints following TKA. Furthermore, five of the patients involved in this analysis had undergone a second TKA on the contralateral side within the first post-operative year of the initial TKA. It is therefore reasonable to suggest that some patients may not have been as active as expected within the first post-operative year. This may have influenced the overall results recorded.

Pre-operatives sagittal plane kinematics showed pathological trends typical of end-stage OA [9,26]. These may be explained by the presence of flexion contractures and poor knee strength associated with OA [27-29]. Post-operatively, abnormal traits continued during stance (Figure 3). This may be associated with a delayed recovery as a result of other medical problems or further surgery. Another plausible explanation for this finding is that many patients were adopting a conservative gait during the assessment to lower their centre of mass and increase their stability, due to mistrust and unfamiliarity with the treadmill. It should also be highlighted that many patients did not return for the 1-year appointment, thus it is possible that this dataset may misrepresent the overall population, as those who have the best functional outcome may not have felt it necessary to return post-operatively.

In the frontal plane, the tendency of the operative knee to remain in adduction pre-operatively is likely to have been caused by the varus alignment the majority of knees exhibited at this stage (44/63). Frontal plane kinematics were restored post-operatively [30-32]. This finding suggested that the implant was performing similarly to a natural and healthy knee joint in this plane.

With respect to transverse plane kinematics, our data showed that a small amount of rotation occurred during gait in our patients pre- and post-operatively (Figure 3C). This was consistent with findings reported by Freeman & Pinskerova and Maderbacher and colleagues [33-34]. Our data was also consistent with previous gait studies, which reported that the knee typically remains externally rotated throughout the gait cycle but internally rotates during swing [30-31]. Our results therefore suggest that the movement patterns observed in this plane resembled non-pathological gait 1-year post-operatively, showing that the implant was capable of restoring transverse plane kinematics during gait. We also reported a significant improvement in walking speed post-operatively. Pre-operative walking speeds were comparable to those recorded in OA patients in previously published studies [9,35]. Walking speeds significantly improved post-operatively, potentially explaining some of the kinematic changes observed at 1-year.

Unfortunately, it is not possible to determine from this study whether patients with this implant would be able to complete more demanding tasks such as stair negotiation and slope walking. The long-term outcomes of the implant also remain unknown, meaning we are unable to comment on how long it would take for knee function to fully restore post-operatively. Future research is therefore required to investigate these aspects of the implant design.

A further limitation to this study is that the exact number of patients who suffered from bilateral OA of the knee was not known, as it was not customary at this site to radiograph both knees during elective clinics. Caution must therefore be taken when interpreting the results presented.

The greatest limitation to this study however, is that Medacta GMK-Sphere implant was not directly compared to other commercially available implants. It is therefore not possible to determine how well the implant functions with respect to other designs. A comparison study should be carried out in future to identify any relative functional benefits or limitations this implant may have. Further research should also seek to compare the functional outcome of the Medacta GMK-Sphere TKA to a healthy age-matched group. Unfortunately, we were unable to undertake this assessment in this study as we did not have ethical approval to involve healthy volunteers. Such a comparison would be vital to support the theory that the Medacta GMK-Sphere is capable of restoring knee range of motion, strength and gait kinematics and replicate knee function of healthy age-matched peers.

**Conclusion**

TKA is becoming increasingly common in younger and more active individuals, but many traditional implant designs fail to allow patients to return to their activities of daily living post-operatively. Patients implanted with the Medacta GMK-Sphere TKA were shown in this study to have significantly improved knee ROM post-operatively. Gait kinematics also improved, especially in the frontal plane. These findings suggest that this implant is capable of restoring joint kinematics within 1-year of the operation. However, the patients may be limited to the activities they may be able to complete due to continued poor knee strength. Patients may therefore benefit from strength training to improve their outcomes.

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**Author Contributions**

GFT – Responsible for design of study, acquisition, analysis and interpretation of data, writing, revising and approving the final manuscript.

LCB – Responsible for conception and design of study and revising and approving the final manuscript.

PJR – Responsible for conception and design of study and interpretation of data, revising and approving the final manuscript.

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The funders of this study were not directly involved with this study or the writing of this manuscript.

**Competing Interests Statement**

LCB is on the speaker bureau at Medacta International.

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Figure Legends

Figure 1: An image of the GMK Sphere Implant, highlighting compartmental design (Source: Medacta International)

Figure 2: Patellar groove design (Source: Medacta International)

Figure 3: Mean sagittal (A), frontal (B), and transverse (C) plane knee kinematics during treadmill walk in 27 patients.

Table 1: Mean range of motion (± SD) of both knees pre- and post-operatively in all patients (above) and in the subset of patients who underwent all assessments (below), and p-values for paired t-tests between operative and contralateral knees pre- and post-operatively.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Stage | Knee | Active ROM° | p-Value | Passive ROM° | p-Value |
| Pre-Operative(n = 63) | Operative Knee | 100.6 (21.8) | - | 102.0 (22.3) | - |
| Contralateral Knee | 110.3 (19.2) | 109.8 (19.0) |
| 1 Year Post-Operative(n = 30) | Operative Knee | 116.1 (19.0) | - | 114.7 (18.3) | - |
| Contralateral Knee | 115.1 (24.0) | 116.1 (23.8) |
| Pre-Operative (n = 27) | Operative Knee | 100.7 (23.0) | 0.004\* | 98.6 (20.9) | <0.0001\* |
| Contralateral Knee | 108.1 (24.2) | 108.6 (22.4) |
| 1 Year Post-Operative (n = 27) | Operative Knee | 114.3 (18.9) | 0.312 | 115.9 (19.7) | 0.661 |
| Contralateral Knee | 118.8 (23.4) | 117.5 (24.0) |

*\*Statistical Significance*

Table 2: Mean (± SD) maximum knee flexor and extensor strength pre- and post-operatively in all patients (above) and in the subset of patients who underwent all assessments (below), and p-values for paired t-tests between operative and contralateral knees pre- and post-operatively.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Stage | Knee | Max Flexor Strength (Nm) | p-Value | Max Extensor Strength (Nm) | p-Value |
| Pre-Operative(n = 63) | Operative Knee | 49.2 (11.7) | - | 45.2 (10.7) | - |
| Contralateral Knee | 53.9 (18.9) | 47.1 (10.8) |
| 1 Year Post-Operative(n = 30) | Operative Knee | 44.3 (3.7) | - | 44.3 (7.6) | - |
| Contralateral Knee | 45.8 (4.5) | 44.6 (6.7) |
| Pre-Operative(n = 27) | Operative Knee | 51.1 (11.6) | 0.026\* | 46.9 (13.6) | 0.039\* |
| Contralateral Knee | 57.2 (21.2) | 48.1 (10.5) |
| 1 Year Post-Operative(n = 27) | Operative Knee | 45.8 (4.2) | 0.346 | 39.5 (5.0) | 0.413 |
| Contralateral Knee | 45.9 (4.6) | 44.7 (6.9) |

*\*Statistical Significance*

Table 3: Mean (±SD) knee kinematics in sagittal, frontal and transverse planes during key events of the gait cycle in pre- and post-operative total knee arthroplasty patients.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Sagittal plane | Frontal Plane | Transverse Plane |
|  | **Operative Knee** | **Contralateral Knee** | **Operative Knee** | **Contralateral Knee** | **Operative Knee** | **Contralateral Knee** |
| Event | **Pre-Operative (n = 63)** | **Post-Operative** **(n = 30)** | **Pre-Operative** **(n = 63)** | **Post-Operative** **(n = 30)** | **Pre-Operative (n = 63)** | **Post-Operative** **(n = 30)** | **Pre-Operative (n = 63)** | **Post-Operative** **(n = 30)** | **Pre-Operative (n = 63)** | **Post-Operative** **(n = 30)** | **Pre-Operative (n = 63)** | **Post-Operative** **(n = 30)** |
| Initial Contact | 20.0(10.0) | 28.2(11.7) | 21.8(9.3) | 25.6(9.9) | -0.7(10.8) | 1.7(9.6) | 1.9(10.9) | 0.5(9.9) | -5.9(10.3) | -7.2(8.5) | -6.5(9.6) | -5.4(10.8) |
| Loading Response | 19.6(10.0) | 27.6(11.5) | 21.3(9.1) | 25.2(9.7) | -0.7(10.8) | 1.9(9.4) | 2.0(10.7) | 0.7(9.9) | -5.9(10.3) | -7.1(8.4) | -6.6(9.9) | -5.5(10.7) |
| Mid-Stance | 18.7(9.6) | 25.6(11.7) | 19.1(8.4) | 24.1(9.9) | -0.9(11.3) | 2.6(9.6) | 2.3(10.4) | 1.2(9.9) | -6.2(10.5) | -6.4(8.4) | -5.7(10.8) | -6.2(10.8) |
| Terminal Stance | 18.3(16.7) | 17.4(7.3) | 12.5(7.8) | 15.6(7.9) | -1.1(11.6) | 3.4(8.1) | 2.8(10.1) | 2.8(10.5) | -6.2(10.8) | -6.5(7.2) | -6.0(9.8) | -7.1(10.5) |
| Mid-Swing | 43.8(14.6) | 58.3(9.5) | 48.3(11.6) | 52.1(11.9) | -5.6(9.6) | -3.0(8.2) | -3.7(12.7) | -5.6(7.9) | -5.0(10.4) | -4.9(7.9) | -3.0(10.8) | -1.3(11.5) |
| Excursion in Stance | 5.6(1.1) | 15.0(4.8) | 11.3(3.7) | 14.6(4.7) | 0.9(0.2) | 2.2(0.6) | 1.2(0.4) | 2.9(0.9) | 0.4(0.1) | 0.8(0.2) | 1.0(0.3) | 1.8(0.5) |
| Excursion in Swing | 23.9(8.4) | 30.1(10.6) | 28.5(9.8) | 26.5(9.3) | 3.9(1.3) | 6.0(1.8) | 5.8(2.1) | 6.9(2.3) | 0.9(0.3) | 2.5(0.9) | 3.4(1.1) | 4.6(1.5) |
| Event | **Pre-Operative (n = 27)** | **Post-Operative** **(n = 27)** | **Pre-Operative (n = 27)** | **Post-Operative** **(n = 27)** | **Pre-Operative (n = 27)** | **Post-Operative** **(n = 27)** | **Pre-Operative (n = 27)** | **Post-Operative** **(n = 27)** | **Pre-Operative (n = 27)** | **Post-Operative** **(n = 27)** | **Pre-Operative (n = 27)** | **Post-Operative** **(n = 27)** |
| Initial Contact | 19.1(8.6) | 27.1(10.4) | 24.8(6.8) | 24.6(8.3) | -2.3(11.1) | 1.7(10.0) | 1.6(10.0) | 0.4(9.7) | -6.5(11.1) | -7.9(8.6) | -6.2(9.0) | -5.0(10.9) |
| Loading Response | 18.5(8.5) | 26.6(10.1) | 24.3(6.8) | 24.4(8.1) | -2.2(11.3) | 1.9(9.9) | 1.7(9.9) | 0.5(9.7) | -6.6(11.2) | -7.8(8.4) | -6.6(9.5) | -5.1(10.8) |
| Mid-Stance | 16.4(8.2) | 25.2(10.4) | 21.9(6.3) | 23.5(8.3) | -2.5(12.4) | 2.5(10.0) | 1.8(9.6) | 0.8(9.7) | -7.6(11.8) | -6.9(8.6) | -5.4(9.4) | -5.5(10.9) |
| Terminal Stance | 13.7(11.4) | 17.8(7.5) | 13.8(8.6) | 15.4(8.2) | -2.1(13.3) | 3.2(8.2) | 3.1(9.4) | 2.1(10.2) | -7.7(12.3) | -6.8(7.1) | -5.6(8.6) | -6.2(10.5) |
| Mid-Swing | 44.3(13.5) | 57.9(9.7) | 48.2(10.5) | 51.5(12.0) | -5.5(10.1) | -3.0(8.7) | -1.9(13.8) | -5.8(8.1) | -5.2(11.5) | -5.4(8.0) | -4.7(10.0) | -1.0(12.1) |
| Excursion in Stance | 7.2(2.1) | 14.8(4.3) | 13.2(4.4) | 14.8(4.4) | 0.8(0.2) | 1.9(0.5) | 1.9(0.7) | 2.2(0.7) | 1.3(0.3) | 1.1(0.3) | 1.4(0.3) | 1.4(0.4) |
| Excursion in Swing | 25.3(9.1) | 30.7(10.8) | 28.8(9.2) | 26.8(9.4) | 3.2(1.1) | 5.7(1.8) | 4.3(1.3) | 6.4(2.2) | 1.7(0.5) | 2.8(1.0) | 1.4(0.3) | 4.0(1.4) |
| *The data presented in the top half of the table was used in the statistical analyses of operative vs. contralateral knees (n = 63 pre-operatively & n = 30 post-operatively), whereas the data in the bottom half of the table was used in statistical analyses of pre- vs. post-operative change in the operative knee (n = 27).* |

Table 4: Results of paired t-tests comparing the kinematic data of operative and contralateral knees during specific gait events pre- and post-operatively (n = 63 & 30, respectively).

|  |  |  |  |
| --- | --- | --- | --- |
|  | Sagittal Plane(p-Value) | Frontal Plane(p-Value) | Transverse Plane(p-Value) |
| Gait Event | Pre-Operatively | Post-Operatively | Pre-Operatively | Post-Operatively | Pre-Operatively | Post-Operatively |
| Initial Contact | 0.241 | 0.113 | 0.154 | 0.638 | 0.747 | 0.498 |
| Loading Response | 0.277 | 0.147 | 0.149 | 0.622 | 0.719 | 0.539 |
| Mid-Stance | 0.765 | 0.228 | 0.085 | 0.576 | 0.814 | 0.935 |
| Terminal Stance | 0.013\* | 0.168 | 0.037\* | 0.794 | 0.926 | 0.817 |
| Mid-Swing | 0.836 | <0.0001\* | 0.442 | 0.281 | 0.220 | 0.096 |

*\*Statistical Significance*

Table 5: Results of paired t-tests comparing the kinematic data of specific gait events from the operative knee pre- and post-operatively (n = 27).

|  |  |  |  |
| --- | --- | --- | --- |
| Gait Event | Sagittal Plane(p-Value) | Frontal Plane(p-Value) | Transverse Plane(p-Value) |
| Initial Contact | 0.000\* | 0.034\* | 0.315 |
| Loading Response | <0.0001\* | 0.019\* | 0.466 |
| Mid-Stance | 0.032\* | 0.011\* | 0.358 |
| Terminal Stance | 0.054\* | 0.009\* | 0.838 |
| Mid-Swing | 0.000\* | 0.071 | 0.067 |





