Native knee kinematics are reproduced during the golf swing after total knee arthroplasty apart from rotation: A case control study of hip and knee kinematics of patients returning to golf compared to match controls

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ABSTRACT

Objectives: Golf is a popular sport in older adults and this same population has an increasing prevalence of osteoarthritis affecting major joints such as the knee. To the authors’ knowledge, the effect of Total Knee Arthroplasty (TKA) on the movements in the golf swing has not been extensively investigated despite the large prevalence of golfers who have undergone TKA. We aimed to determine lower limb joint kinematics during the golf swing and whether these are influenced following TKA.

Methods: A case-control study was undertaken with ten right-handed golfers who had undergone TKA (cruciate-retaining single radius implant) and five matched golfers with native knees. Each golfer performed five swings with a driver whilst being recorded at 200 Hz by a ten-camera motion capture system. Knee and hip three-dimensional joint angles (JA) and joint angular velocities (JAV) were calculated and statistically compared between the groups at six swing events.

Results: The left knee demonstrated large effect sizes for lower external rotation during take away, mid (p = 0.01) and top of backswing in the TKA group. In contrast, the right knee demonstrated large effect sizes for lower external rotation in the TKA group during the downswing, contact and follow-through phases. There were no differences in knee flexion/extension, ab/adduction, or JAV between the groups. Both hips demonstrated statistically significantly (p = 0.02 for left and p = 0.04 for right) lower flexion in the TKA group during the takeaway swing event, and lower internal rotation in the backswing and greater external rotation in the downswing of the right hip.

Conclusion: Normal knee kinematics were observed during the golf swing following TKA, with the exception of reduced external rotation in the left knee during the backswing and the right during the down swing. The differences demonstrated in the hip motion indicate that they may make compensatory movements to adjust to the reduced external rotation demonstrated in the knee.

Level of Evidence: IV.

What are the new findings

- The first study to describe the kinematics of the knee and hip during the golf swing using an infra-red camera tracking system and compares these in patients that have returned to golf after total knee arthroplasty to matched control golfer with native knees.
- Golfers returning to their sport following cruciate-retaining total knee arthroplasty demonstrated knee kinematics similar to native knee during the golf swing with the exception of external rotation.
INTRODUCTION

Golf is a popular sport among older adults who participate as a form of recreation, exercise and social interaction [1]. However, this population has an increasing prevalence of osteoarthritis affecting major joints such as the knee. The ageing population has been associated with rising numbers of Total Knee Arthroplasty (TKA) being performed in the UK, with the number of knee replacements rising to above 108,000 in 2022 [2,3]. Many patients cite that their main functional goal is returning to golf [4]. TKA is an excellent method of deformity correction, pain relief and restoration of function [5] with 83% of patients having no pain after TKA [1,6,7], and a significant improvement in the ability to play golf [5,8]. There is significant variation in the reported portion of patients who return to golf after TKA, ranging from 29.4% to 81.5% [9,10]. Although TKA component design/type has not been shown to make a difference in return to golf, unicompartamental knee replacement (UKR) has a higher rate of return to golf with studies reporting 100% return to golf [9], with the Knee Society recommending a return to golf after TKR [11]. Studies of external knee joint moments in healthy golfers have found that repeated loading can be linked with osteoarthritis [12,13].

The effect of TKA on the golf swing has not been extensively investigated despite the large prevalence of golfers who have undergone TKA. Kenny et al. [14] examined whether knee surgery affected golf movements by comparing ten previously injured golfers to five native knee controls and found that TKA participants displayed greater left (lead) knee flexion. Another study evaluated knee 3D kinematics using continuous radiographic assessment to examine the femorobital rotation during golf swings after TKA, reporting higher magnitudes of axial rotation during the golf swing in the trail (right) knee compared to the lead knee [15]. Greater understanding of the golf swing after TKA may allow surgeons to set realistic expectations for future patients and an understanding of knee kinematics continues to be used by implant manufacturers to improve implant designs with the aim of improved TKA outcomes [16]. There is a paucity of literature identifying kinematic swing differences after TKA [17,18] and should these be identified, could aid explanations for why between 18.5 and 70.6% of golfers do not return to golf post TKA [10,11,19]. Furthermore, it could provide information on how knee kinematics during the golf swing are influenced following TKA that may be addressed with implant modification or swing changes that may aid participation in golf post surgery.

The aim of this study was to (1) describe the kinematics of the knee and hip during the golf swing and (2) to compare these in patients that have returned to golf after TKA to match control golfer with native knees. The hypothesis is that for a cruciate-retaining single radius implant, there is no difference in knee kinematics during the golf swing compared to matched controls. This would allow clinicians to provide clear information to patients when deciding on arthroplasty who are keen to return to golf.

METHODS

The present study was a case-control analysis of movements of the lower limbs during the swing in golfers with TKA compared to a matched control group of golfers with native knees. Ethical approval was granted from the University of Edinburgh Ethics Committee.

Male patients who underwent cruciate-retaining single radius implant TKA in 2014 at a university teaching hospital were identified and, if golf was recorded in their history, were invited to take part in the study. All participants had rehabilitated for at least 2 years post TKA. Inclusion criteria were that participants must have had a primary TKA to either or both knees, a minimum postoperative follow-up of 6 months [17,18], have no known osteoarthritis in other joints, be asymptomatic and fully rehabilitated to return to golf. Fifteen right-handed golfers were split into two groups: a TKA group (n = 10) consisting of participants with a primary TKA to one or both knees, and a control group (n = 5) consisting of age- and mass-matched golfers who were free from musculoskeletal injury. The TKA group contained four participants with left knee replacements, four with right knee replacements and two with both knees replaced. All patients received single radius cruciate-retaining implants (Triathlon, Stryker, Kalamazoo, USA).

Each participant’s body mass and height were measured and their date of birth, golfing handicap (A golf handicap is a numerical measure of a golfer’s ability, which is used to enable players of different abilities to compete against one another) and details about their TKA (side(s), time post-operation) were recorded prior to testing. Participants were unclad except for tightly fitting stretch-fabric shorts. A single trained experimenter applied 12.5 mm reflective markers with double-sided tape to the following anatomical landmarks on both sides of the body: 1st metatarsals, 5th metatarsals heads, calcanei, lateral & medial malleoli, lateral & medial epicondyly, greater trochanter of the femurs, iliac crest, PSIS (posterior superior iliac spines), ASIS (anterior superior iliac spines), acromion processes. Rigid tracking clusters with four 12.5 mm reflective markers were applied bilaterally to each shank and thigh mid-way between knee and ankle and hip and knee respectively. This marker set was based upon the calibrated anatomical systems technique (CAST) [20].

Participants used a standard driver (R5 Dual, Taylormade, Carlsbad, CA, USA). The club shaft was fitted with 10 mm reflective tape directly below the grip and 500 mm down the shaft, and the clubhead had a 12.5 mm reflective marker placed on its dorsal surface. A standard golf ball covered in reflective tape was also used.

The swings were recorded by nine infrared cameras operating at 200 Hz (Pro-Reflex MCU 500, Qualisys AB, Göteborg, Sweden) in a biomechanics laboratory of dimensions 12 m × 8 m × 5 m.

EXPERIMENTAL PROTOCOL

Participants stood on artificial grass surface with the ball on a wooden 50 mm tee. A net was positioned 2.5 m away with a target marked on its netting. A capture volume of approximately 6 m × 6 m × 2.5 m was calibrated before each data collection session using a 750 mm wand. A static trial, conducted with the participant standing upright with both arms abducted to the horizontal, was performed. Participants were then asked to hit five of their normal drives into the net.

Data processing

The static and movement trials were processed using Qualisys Track Manager (QTM version 2018.1) and exported as C3D files to Visual 3D (Visual 3D, C-motion Inc. Germantown, MD, USA). Data were filtered using a low-pass 4th order Butterworth filter with individual cut-offs for each marker [13] and joint angles (JAs) were calculated using an X-Y-Z Cardan sequence. Positive JAs around the X, Y and Z axes represented flexion, abduction and external rotation for left and right knees and hips. Joint angular velocities (JAVs) were then calculated as the first derivative of the JAs. As all golfers were right-handed the left leg was the lead leg and the right leg the trail leg.

Six swing events were identified as shown in Fig. 1: Takeaway (TA: clubhead linear speed crossed a threshold value of −0.2 ms−1); Mid-Backswing (MBS: club shaft was parallel to the ground during the backswing); Top of Backswing (TBS: the clubhead linear velocity in the global X direction reached zero); Mid-Downswing (MDS: club shaft was parallel to the ground during the downswing); Ball Contact (BC: the frame immediately prior to the ball recording a positive linear speed) and Mid-Followthrough (MFT: club shaft was parallel to the ground after ball contact). Three swing phases were delineated by these four events: Backswing (TA to TBS), Downswing (TBS to BC) and Followthrough (BC to MFT).

Statistical analysis

Data were analysed using SPSS software (SPSS version 25, IBM, USA). First data were tested for normality with Shapiro–Wilk tests and for Homogeneity of Variance using Levene’s tests, both with α-level of 0.05.
Differences in JAs and JAVs between TKA participants and controls over the course of the six swing events were then examined separately for each joint using repeated measures 2-way ANOVA with one between-subject factor and one within-subject and (group x swing event) with α-level of 0.05. Effect sizes (ES) were assessed using Partial Eta Squared ($\eta^2_p$) with the following thresholds: Large 0.1379; Medium 0.0588; Small 0.0099 [21]. The swing event’s main effect and swing event x group interaction were assessed for sphericity by the Mauchly test ($p$). If data were non-normal, the simple effects were re-assessed for sphericity by the Greenhouse-Geisser Epsilon was used to adjust the degrees of freedom.

It was expected that values for JAs and JAVs would be different between each swing event, so if the swing event’s main effect was statistically significant, pairwise post-hoc tests were not computed. If the interaction was statistically significant, simple effects were used to examine the difference between TKA and control group at each swing event [22]. If data were non-normal, the simple effects were re-assessed using independent groups t-tests using bootstrapping [22]. If the Levene tests showed heterogeneity of variance between groups, the degrees of freedom of the simple effects were adjusted appropriately before calculating the level of significance. Effect size of the simple effects was again assessed with Partial Eta Squared.

RESULTS

The TKA group had a mean ± standard deviation (SD) age of 66.0 ± 5.9 years and handicap 17.7 ± 5.1 (Table 1) whilst the control group values were 63.2 ± 8.2 years and 19.4 ± 5.8 respectively (Table 2).

Knee joint

There were statistically significant main effects for swing event for all axes for both knees. Fig. 2a–c shows the JAs around each knee axis, and there were no group or interaction differences in movements around the flexion-extension and the abduction-adduction axes. In the external–internal rotation axes (Fig. 2c), there were significant interactions for both knees. For the left knee, there was a statistically significant difference between the groups at TA ($p = 0.03$) and MBS ($p = 0.01$) and large effect sizes at TA, MBS and TBS, with the TKA golfers having less external rotation than the controls. In contrast, the right knee demonstrated large effects at MDS, BC, and MFT with TKA participants having less external rotation, but these were not statistically significant. Despite TKA participants having less external rotation there were no statistically significant differences in internal/external JAV in the knee (Fig. 3a), as well as no differences in adduction/abduction JAV (Fig. 3b) or internal/external rotation JAV (Fig. 3c).

Hip joint

There were statistically significant main effects for events for both hips. The JAs for left and right hips around the three axes of rotation (Fig. 4a–c). There were statistically significant differences at TA ($p = 0.02$ for left and $p = 0.04$ for right) with large effect sizes, and a large effect size at MBS for the right hip, with less hip flexion in the TKA group. There was a statistically significant interaction ($p = 0.03$) for the left hip around the abduction-adduction axis and although simple effects did not identify any statistically significant differences, there were large effect sizes at all swing events with the TKA group having lower abduction in the backswing and lower addition in the downswing. Finally, there was a statistically significant group effect between the TKA and control groups for external–internal rotation in the right hip, with the TKA group having statistically significantly ($p = 0.03$) lower internal rotation in the backswing and greater external rotation in the downswing (Fig. 4c).

DISCUSSION

This study has defined the kinematics of the knee and hip during the golf swing in both the native knee joint and those that underwent TKA. There were limited differences in knee kinematics during the golf swing between those with and without a TKA, with the exception of reduced external rotation in the left knee during the backswing and the right during the down swing. A similar pattern was observed in the hip, with the only difference being less flexion in the TKA group during the take-away swing event and lower internal rotation in the backswing and greater external rotation in the downswing of the right hip.

During the backswing, the left knee flexed and the right knee extended for both groups. Although there was slightly less range of movement in the TKA group, this was not statistically significant. During the downswing and follow-through phases, the knees’ movements were reversed with the left knee extending and the right knee flexing, again with the TKA golfers showing slightly less movement. Therefore, the data for the present study does not support the findings of the only previous study comparing golfers after knee surgery and normal golfers [14], which reported that there was a greater mean and range of knee flexion in the surgical group than the controls. This may have been due to different surgeries (TKA, ACL reconstruction and arthroscopy) being included in that study's experimental group causing larger variation. This was not shown in the current study and in addition, there was smaller

Table 2

<table>
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<tr>
<th>Participant</th>
<th>Age (years)</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
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<td>1.79</td>
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</table>
variance in the TKA group than the control golfers for knee flexion. The
graphs of knee flexion-extension for the TKA golfers were similar to those
in the previous study using X-ray videography [15] although the latter
did not report values for MDS or BC swing events, which may be due to
the low sampling frequency.

The only statistically significant differences in the knee kinematics
during the golf swing were shown in the external-internal rotation.
During the backswing, the control group had statistically significantly
more external rotation at MBS in the left knee than the TKA group, with
large effect sizes for the differences throughout the whole phase. In the
downswing and follow through, the control group demonstrated greater
external rotation in the right knee, with large effect sizes at all swing
events. Comparisons with the graphs of Hamai et al. [15] showed simi-
larities in shape, although there was slightly less external rotation in
the left knee in the current TKA group. This difference may relate to the fact
that during the TKA employed in this study (Triathlon, Stryker) although
it was cruciate-retaining (posterior cruciate ligament only), the anterior
cruciate ligament was removed and this is a primary stabiliser of rotation
in the knee joint. There are recognised differences in knee kinematic
between cruciate-retaining and sacrificing (used in the current study)
TKA and this may explain the observed difference in rotation between the
two groups [23]. In contrast to UKR in which the ACL is retained, and one
of the ACL functions is to provide rotational stability. Considering the
forces experienced by the knee during the golf swing are comparatively
large to forces generated in the knee in daily life [24,25]; the large
external-internal rotation forces experienced in the knee during the golf
swing could exaggerate any feelings of instability and the loss of ACL
could be a factor leading to the 18.5–70.6% of people post TKA who
report not being able to return to golf [9,10]. In contrast to the much
higher rate of return to golf post UKR of up to 100% [9]. The participants

Fig. 2. a. Flexion/extension angles (°) of the left and right knee joints during the swing. Positive values represent flexion. b. Abduction/adduction angles (°) of the left and right knee joints during the swing. Positive values represent flexion. c. External/internal rotation angles (°) of the left and right knee joints during the swing. Positive values represent external rotation. Symbol * indicates statistically significant difference (P < 0.05) between groups at specific swing events. Symbol # represents large effect size difference between groups at specific swing events.

Fig. 3. a. Flexion/extension joint angular velocities (°\(\cdot\)s\(^{-1}\)) of the left and right knee joints during the swing. b. Abduction/adduction joint angular velocities (°\(\cdot\)s\(^{-1}\)) of the left and right knee joints during the swing. c. External/internal rotation joint angular velocities (°\(\cdot\)s\(^{-1}\)) of the left and right knee joints during the swing.
in this study had returned to golf following TKA and no participants who had ceased playing golf were selected to take part in the study. As well as the bony mechanical differences between TKA and native knees, the neurosensory differences and altered muscle control may play a role in the return to golf. We were unable to quantify any of these differences in the current study.

Hip motion showed statistically significantly less flexion in left and right hips in the TKA group at TA and a large effect for the right hip at MBS, Fig. 4.

**Fig. 4.** a. Flexion/extension angles of the left and right hip joints during the swing. Positive values represent flexion. Symbol * indicates statistically significant difference (P < 0.05) between TKA and control groups at specific swing events. Symbol # represents large effect size difference between groups at specific swing events. b. Abduction/adduction angles (°) of the left and right hip joints during the swing. Positive values represent abduction. Symbol # represents large effect size difference between groups at specific swing events. c. External/internal rotation angles (°) of the left and right hip joints during the swing. Positive values represent external rotation. Symbol + represents group main effect difference (P < 0.05) between over the whole swing.
indicating less movement during the backswing. However, there were no statistically significant differences in the downswing or follow through. The TKA group showed lower left hip abduction (with large effect size) in the backswing and lower adduction in the downswing and follow through. Finally, there were statistically significant differences between the TKA and control groups over the whole swing in the right hip for external-internal rotation, with the TKA golfers having less internal rotation at TA and MBS and more external rotation from TBS to BC. All of these differences suggest that TKA golfers were reducing their range of hip motion, particularly in the backswing. The only statistically significant difference in JAV was that TKA golfers had lower extension velocities, particularly in the downswing. The reduction in hip movements may have been linked to a reduction in weight shift, but without ground reaction forces, this is again difficult to confirm. Alternatively, this might be a secondary reaction to the reduced rotation observed at the knee in the TKA group, which may be related to limited rotational stability associated with a TKA implant as discussed above. There were fewer differences in joint angle velocities suggesting that the total knee arthroplasty golfers were able to use the lower limbs to generate clubhead motion.

The strength of this study was using highly accurate motion capture technology to show a TKA is able to replicate the golf swing, a dynamic compound movement, without substantial changes.

There were several limitations to the current study. All participants had returned to golf following TKA and so the study has a survivorship bias. Future studies could assess differences in knee kinematics between those that were able and those that were not able to return to golf, due to their knee pathology, to assess whether there are differences between these groups. Sample sizes were relatively small with only ten TKA patients and five controls, due to the considerable testing time required for each participant. Also, the TKA group contained golfers who had right, left or both knees replaced, but results were pooled for all participants. Ideally, the TKA data would have been separated into three different subgroups, but statistical power would then have been even lower.

CONCLUSION

This study has shown that there are limited differences in knee and hip kinematics between golfers with total knee arthroplasty and those without, with the only difference in knee motion external-internal rotation and hip flexion-extension. There was little evidence of major swing differences between groups, and therefore golfers had maintained or relearned their golf swing after total knee arthroplasty and could successfully drive the ball.

Authors’ contributions

CSR: conception, data collection, data analysis, manuscript writing. SC: conception, data collection, data analysis, manuscript editing. IRM/PGR/NDC: Conception, Data collection, editing of manuscript.

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No funding was received.

Consent for publication

Only anonymous data were analyzed and used in this study in accordance with the ethics department at the study centre.

Ethics approval and consent to participate

Ethical approval was granted from a University Ethics Committee. All participants consented to be included. The project was registered with the institutions audit department and was conducted in accordance with the Declaration of Helsinki and the guidelines for good clinical practice.

Declaration of competing interest

The authors declare no competing interests.

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References


