Lower-limb kinematics and joint moments during high-impact tasks after hip and knee arthroplasties

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Lower-limb kinematics and joint moments during high-impact tasks after hip and knee arthroplasties

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Abstract

High-impact physical activity delivers musculoskeletal and systemic health benefits yet remains controversial for people with hip or knee arthroplasties. This study investigates the three-dimensional kinematics and kinetics of high-impact tasks in high-functioning adults with total hip arthroplasty (THA, n = 11), total knee arthroplasty (TKA, n = 4), or unicompartmental knee arthroplasty (UKA, n = 3), compared with healthy controls (n = 57) from prior studies. They completed running, 45° change of direction (COD), countermovement jumps (CMJs), and unilateral/bilateral hopping. An 8-segment biomechanical model was used to quantify 3D joint angles and internal moments. These were time-normalised and modelled using Generalized Additive Models with covariates for group, age, and task intensity. Post-hoc contrast with controls was undertaken and reported. THA participants ran with lower hip abduction angle (peak Δ6.22°), lower external rotation angle (peak Δ7.38°), and greater hip extensor moment (peak Δ1.19 Nm/kg). During jumping and hopping tasks, THA participants also showed greater hip extensor moments (peak Δ0.41–0.67 Nm/kg), compared to controls. People with TKA and UKA consistently exhibited reduced knee extensor moments across high-impact tasks. Altered transverse-plane knee mechanics were observed in TKA and UKA, characterised by lower knee external rotation angle (peak Δ8.58°–12.54°), together with reduced internal rotation moments (peak Δ0.3 Nm/kg). High-functioning individuals with hip and knee arthroplasties can perform high-impact activities, but with altered movement strategies. The long-term implications of these biomechanical adaptations for implant loading and durability remain unclear and warrant further investigation.

Keywords: Arthroplasty, Sports, Biomechanics, Running, Side-step cutting, Hopping, Return to sport, Total hip arthroplasty, Total knee arthroplasty

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High-impact physical activity delivers musculoskeletal and systemic health benefits yet remains controversial for people with hip or knee arthroplasties. This study investigates the three-dimensional kinematics and kinetics of high-impact tasks in high-functioning adults with total hip arthroplasty (THA, n = 11), total knee arthroplasty (TKA, n = 4), or unicompartmental knee arthroplasty (UKA, n = 3), compared with healthy controls (n = 57) from prior studies. They completed running, 45° change of direction (COD), countermovement jumps (CMJs), and unilateral/bilateral hopping. An 8-segment biomechanical model was used to quantify 3D joint angles and internal moments. These were time-normalised and modelled using Generalized Additive Models with covariates for group, age, and task intensity. Post-hoc contrast with controls was undertaken and reported. THA participants ran with lower hip abduction angle (peak Δ6.22°), lower external rotation angle (peak Δ7.38°), and greater hip extensor moment (peak Δ1.19 Nm/kg). During jumping and hopping tasks, THA participants also showed greater hip extensor moments (peak Δ0.41–0.67 Nm/kg), compared to controls. People with TKA and UKA consistently exhibited reduced knee extensor moments across high-impact tasks. Altered transverse-plane knee mechanics were observed in TKA and UKA, characterised by lower knee external rotation angle (peak Δ8.58°–12.54°), together with reduced internal rotation moments (peak Δ0.3 Nm/kg). High-functioning individuals with hip and knee arthroplasties can perform high-impact activities, but with altered movement strategies. The long-term implications of these biomechanical adaptations for implant loading and durability remain unclear and warrant further investigation.

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Introduction

In the United Kingdom (UK) alone, 108,558 and 116,845 primary hip and knee arthroplasties were undertaken in 2023, respectively (Registry, 2024). The demand for joint arthroplasty is projected to increase by 40% by 2060 (Matharu et al., 2022), and patients receiving a joint arthroplasty are becoming younger (Kurtz et al., 2009). Younger patients are at greater risk of requiring revision of joint arthroplasty surgery (Bayliss et al., 2017), are more active and have greater expectations of returning to vigorous physical activity (PA) compared to older adults (Ponzio et al., 2021).

People with a joint arthroplasty are traditionally advised to participate in low-impact PA (Lester et al., 2022; Sowers et al., 2023) and avoid vigorous, high-impact PA and sports, because of concerns regarding implant safety and longevity (Mooiweer et al., 2022). However, the World Health Organisation recommends that adults accumulate at least 75–150 min/week of vigorous-intensity aerobic PA (or an equivalent combination of moderate- and vigorous-intensity activity). Vigorous PA may involve high-impact tasks like running, jumping, landing, and change of direction tasks. High-impact PA have many superior health benefits over low-impact activities, such as being a better stimulus for bone adaptation (Allison et al., 2015). High-impact PA may be relevant to people with a joint arthroplasty, given that they are at an age, or growing into the age, where the risk of osteoporosis is greater (Clynes et al., 2020).

Observational studies have reported that high-impact activities do not increase the rates of joint arthroplasty revision (Kornuijt et al., 2022; Shah et al., 2025). However, these studies focus primarily on surgical revision as the outcome. Understanding the kinematics and kinetics of how people with a total hip or knee joint arthroplasty perform high-impact tasks is crucial for understanding the implant loads and for informing potentially safer technique modification strategies. Many biomechanical studies in people with joint arthroplasties have focused only on low-impact activities, such as walking (Dong et al., 2023; Lunn et al., 2019; Moyer et al., 2018). Far fewer studies have investigated the biomechanics of high-impact tasks in people with a joint arthroplasty (Harvey et al., 2024). Some studies investigated patients with an instrumented joint implant to quantify joint contact forces (Bergmann et al., 2016; Bergmann et al., 2014; Bergmann et al., 1993). These studies have not considered a wider range of high-impact activities beyond running, like hopping and countermovement jumps (CMJs) (Altai et al., 2024). Additionally, previous studies have not specifically included patients who have successfully returned to high-impact PA (Bergmann et al., 2016; Bergmann et al., 2014; Bergmann et al., 1993; Harvey et al., 2024).

This study aims to quantify the three-dimensional (3D) joint angles and moments during high-impact tasks in high-functioning people with hip or knee arthroplasties. We hypothesise that high-functioning people with hip or knee arthroplasties would demonstrate altered 3D hip or knee kinematics and kinetics compared to healthy controls. These findings are intended to provide preliminary biomechanical evidence to inform future PA recommendations and implant load-testing protocols.

Methods

Participants

Participants with a total hip arthroplasty (THA, n = 11), total knee arthroplasty (TKA, n = 4), or unicompartmental knee arthroplasty (UKA, n = 3) were enrolled. Participants were eligible if they were 1) between 18 years and 85 years old, 2) had undergone THA, TKA, or UKA surgery ≥ 1 year before enrolment, 3) self-reported returning to recreational or competitive high-impact PA, 4) reported no pain at the joint arthroplasty site, and 5) were free from any medical conditions that preclude safe participation in vigorous-intensity PA. All participants provided written informed consent, and the study was approved by the Health Research Authority Research Ethics Committee (IRAS 327418).

Data from healthy participants were obtained from prior studies (Altai et al., 2024; Liew et al., 2020). Forty (20 males, 20 females) healthy participants from Altai et al. (Altai et al., 2024) were included, with an average age, mass, and height of 40.3 (13.1) years, 68.4 (11.7) kg, and 1.7 (0.1) m, respectively. Seventeen (10 males, 7 females) healthy participants from Liew et al.

(Liew et al., 2020) were included, with an average age, mass and height of 22.5 (3.1) years, 68.0 (12.0) kg, and 1.7 (0.1) m, respectively.

Experimental protocol

Participants with a joint arthroplasty performed all trials while wearing their usual running shoes and exercise attire. For running, participants performed at least three successful trials at a comfortable self-selected pace. For the COD45, participants ran at a comfortable pace before performing a 45° side-step cutting manoeuvre with their operated limb towards the contralateral direction. For running and COD45, a lead-up and tail-off distance of 10m was provided. For CMJs, participants performed three separate repetitions of maximal effort CMJs, each at the preferred descent depth, with the arms held in a "T" position (90° shoulder abduction). For hopping, participants performed two sets of bilateral and unilateral (operated limb) hops at 2.6 Hz using an auditory metronome. Participants were required to position their arms in a 90° abducted "T" position and hop continuously for 10 s. A minimum of 1 min rest was provided between each repetition of the task to avoid fatigue. Details of the experimental protocol for the data from the healthy participants can be found in the original publications (Altai et al., 2024; Liew et al., 2020), but also summarised in Table SM1 in the supplementary.

Biomechanical model and processing

Retro-reflective markers were adhered to the trunk and lower extremities (Supplementary Material). Marker trajectories were captured using 14 optical motion capture cameras (Vicon Ltd., 200 Hz), while ground reaction forces (GRF) were captured using two in-ground force plates (Kistler, 2000 Hz). Hip joint centres were calculated using a regression equation (Bell et al., 1989). Knee and ankle joint centres were calculated as the midpoint between the medial and lateral femoral condyles and malleoli, respectively (Pohl et al., 2010). An eight-segment trunk-lower extremity kinetic model was created in Visual 3D (Dempster, 1955; Hanavan, 1964).

Both marker trajectories and GRF were filtered at a common cut-off frequency of 18Hz, using a 4^{th} order, bidirectional, zero-lag Butterworth filter (Liew et al., 2016). Details of the biomechanical modelling protocol of the data from the healthy participants can be found in the original publications (Altai et al., 2024; Liew et al., 2020), and summarised in the Supplementary. Three-dimensional (3D) joint angles were calculated using a Cardan XYZ (flexion-extension, abduction-adduction, and axial rotation) rotation sequence (Cole et al., 1993). Internal joint moments were expressed within an orthogonal frame of reference of the proximal segment (Schache and Baker, 2007).

Joint angles and moments were segmented as follows: between consecutive initial contacts of the operated limb for hopping, between initial contact and toe-off for running and COD45 (i.e. stance), and between the onset of the model's centre of mass (COM) descent and toe-off for CMJs. The time-varying joint angle and moment segments were time-normalised to 101 data points for all tasks. The intensity of the five tasks was quantified as mean COM speed (m/s) for running, mean COM approach speed (m/s) for COD45, stance duration (s) for hopping, and the jump height (m) for the CMJ, defined as the difference between peak COM height and standing COM height.

Patient-reported outcome measures

The following data were collected as descriptive measures. The Oxford Hip Score (OHS) and the Oxford Knee Score (OKS) were collected for participants with a hip or knee arthroplasty, respectively (Dawson et al., 1998; Wylde et al., 2005)). The Hip Disability and Osteoarthritis Outcome Score (HOOS) and the Knee Disability and Osteoarthritis Outcome Score (KOOS) were collected for participants who underwent hip or knee arthroplasty, respectively (Nilsdotter et al., 2003; Roos and Lohmander, 2003)). Lastly, the High-Activity Arthroplasty Score (HAAS) was collected (Talbot et al., 2010)).

Statistical analysis

All statistical analyses were conducted using R software. There were nine time-varying joint angles and nine time-varying joint moment dependent variables (Equation 1). The independent variables were groups (Healthy [reference], THA, TKA, UKA), age, task intensity, a group-by-cycle interaction, and a random subject intercept (Equation 1). We used Generalized Additive Modelling (GAM) for modelling (Wood, 2017). The *mgcv (v1.9-3)* package was used for GAM, *tidygam (v1.0.0)* for post-hoc contrast, and performance (v0.16.0) for quantifying the metrics of adjusted R^2, Akaike Information Criterion, and Bayesian Information Criterion (see Supplementary).

$$Outcome_{ij} = \beta_0 + \beta_1(Group_i) + \beta_2(Intensity_i) + \beta_3(Age_i) + f\left(Cycle_{ij}, by\ Group_i\right) + b_i + \varepsilon_{ij} \ldots \text{ (Equation 1)}$$

Where $Outcome_{ij}$ represents the joint angle or moment waveform for participant i, and cycle point j, β_0 represents the intercept, $\beta_{1,\,2,\,3}$ represents the fixed effect of group, task intensity and age, $f\left(Cycle_{ij}, by\ Group_i\right)$ represents the smooth function of cycle varying by group, b_i the random subject intercept, and ε_{ij} the residual error. Smooth functions of cycle were fitted using penalised thin plate regression splines. Smoothing parameters were selected using the default generalized cross-validation/Mallows' Cp criterion, which balances model fit against model complexity. Model residuals were simulated using the *DHARMa* (v0.4.7) package. Residual uniformity was assessed using the Kolmogorov-Smirnov test, which tests whether the simulated residuals deviate from the expected uniform distribution. Given the large number of point-wise observations, model appropriateness was primarily assessed by visual inspection of the QQ-uniform plots, with no substantial evidence of model misspecification observed (Supplementary Material).

A significant difference between groups was determined by a non-zero crossing of the 95% confidence interval (CI). We focus on the report of hip variables for individuals with THA, and the knee variables for people with TKA or UKA.

Results

Table 1 summarises the descriptive characteristics of our patient. There was a significant age difference (P < 0.001), but not height (P = 0.299) and mass (P = 0.373), between the patient and healthy cohorts. Participants with a joint replacement performed the five tasks at different intensities compared to controls (Table 2). Our Supplementary Materials report 1) the cohort and individual joint angle and moment waveforms, 2) statistical fit metrics, and 3) all the significant regions of difference. Below, we report the key differences with 95%CI relative to the control group.

Hip alterations in THA

People with THA ran with a lower abduction angle (peak Δ 6.22° (1.11°, 11.32°)) between 29-100% stance, and a lower external rotation angle (peak Δ 7.38° (2.96°, 11.80°)) between 61-100% stance (Figure 1). This was accompanied by a greater hip extensor moment (peak Δ 1.19 (0.80, 1.57) Nm/kg) between 0-94%, lower hip abduction moment between 45-90% (peak Δ 0.43(0.23, 0.64) Nm/kg) and greater external rotation moment (peak Δ 0.23 (0.10, 0.35) Nm/kg) between 78-100% stance (Figure 2). People with THA performed CMJ with a greater hip flexion (peak Δ17.19° (8.31°, 26.06°)) throughout, and greater external rotation angles (peak Δ5.84° (1.91°, 9.77°) between 19-73% (Figure 1). This was accompanied by a greater hip extensor moment (peak Δ 0.60 (0.48, 0.72) Nm/kg) and a greater adduction moment (peak Δ 0.25 (0.17, 0.33) Nm/kg) largely throughout the jump (Figure 2). Similar trends occurred during unilateral and bilateral hops. There were no hip kinematic differences in THA, whilst the first 50% was a period of greater hip extensor (unilateral peak Δ 0.67 (0.53, 0.81) Nm/kg vs bilateral peak Δ 0.41 (0.34, 0.49) Nm/kg), adduction (unilateral peak Δ 0.51 (0.40, 0.63) Nm/kg vs bilateral peak Δ 0.33 (0.28, 0.39) Nm/kg), and internal rotation moments (unilateral peak Δ 0.16 (0.09, 0.23) Nm/kg vs bilateral peak Δ 0.10 (0.07, 0.13) Nm/kg) (Figure 2). People with THA performed COD45 with greater hip adduction (peak Δ 14.12° (3.22°, 25.02°)) between 20-81% (Figure 1). They also performed COD45 with greater hip flexor moment (peak Δ 1.60 (0.90, 2.31) Nm/kg) largely during 0-79%, and lower external rotation moment (peak Δ 0.63 (0.27, 0.99) Nm/kg) during 4-21% stance (Figure 2).

Knee alterations in TKA & UKA

People with a TKA or UKA ran with a lower knee flexion angle between 44-50% (peak Δ 10.99° (0.10°, 21.89°)), and between 17-33% (peak Δ 13.55° (1.35°, 25.75°)) (Figure 3, 5). People with a TKA, but not a UKA, performed CMJ and bilateral hopping with greater knee flexion angles between 0-55% (peak Δ 31.04° (13.10°, 49.98°)) and 37-59% (peak Δ 9.28° (3.24°, 15.33°)), respectively (Figure 3, 5). In addition, people with UKA performed unilateral hopping with a greater knee flexion angle between 54-63% (peak Δ 7.56° (0.48°, 14.64°)) (Figure 5). People with TKA and UKA exhibited significantly lower knee extension moment across all five tasks. In people with TKA this occurred between 15-83% in running (peak Δ 2.28 (1.11, 3.46) Nm/kg), 63-92% in CMJ (peak Δ 0.68 (0.31, 1.05) Nm/kg), 5-51% in unilateral hops (peak Δ 1.30 (1.03, 1.57) Nm/kg), largely between 0-52% in bilateral hops (peak Δ 0.75 (0.62, 0.89) Nm/kg), and 21-64%

in COD45 (peak Δ 1.18 (0.44, 1.92) Nm/kg) (Figure 4). In people with UKA this occurred between 11-66% in running (peak Δ 2.24 (0.92, 3.56) Nm/kg), 55-88% in CMJ (peak Δ 0.67 (0.25, 1.08) Nm/kg), 0-47% in unilateral hops (peak Δ 1.35 (1.04, 1.65) Nm/kg), 0-37% in bilateral hops (peak Δ 1.02 (0.86, 1.17) Nm/kg), and 19-64% in COD45 (peak Δ 1.28 (0.50, 2.06) Nm/kg) (Figure 6).

There was a lower knee external rotation angle during running between 0-9% and 90-100% stance (peak Δ 8.58° (3.84°, 13.32°)) in people with TKA, and largely between 85-100% in people with UKA (peak Δ 12.54° (7.32°, 17.77°)) (Figure 3, 5). This was associated with a reduced internal moment largely across stance in people with TKA (peak Δ 0.32 (0.17, 0.46) Nm/kg) and UKA (peak Δ 0.33 (0.17, 0.49) Nm/kg) (Figure 3, 5). People with TKA, but not UKA, had reduced internal rotation angle during unilateral and bilateral hopping by 26-36% and 13-31%, respectively (Figure 3, 5). People with TKA and UKA experienced reduced knee internal rotation moment during unilateral. For people with TKA, this occurred between 3-42% (peak Δ 0.10 (0.06, 0.15) Nm/kg) in unilateral (Figure 4). For people with UKA, this occurred between 0-32% (peak Δ 0.11 (0.06, 0.17) Nm/kg) in unilateral (Figure 6).

Discussion

High-functioning individuals with hip and knee arthroplasties performed high-impact tasks, showing some differences in joint motion patterns, but greater differences in joint moments, compared with controls. People with THA performed the activities with greater hip extensor moments, whereas people with TKA and UKA consistently demonstrated reduced knee extensor moments, accompanied by altered knee axial kinematics. These findings support our hypothesis that individuals with hip and knee arthroplasties may perform high-impact tasks using altered biomechanical strategies relative to healthy controls.

To address the possibility that comparisons with healthy controls were influenced by residual between-group differences, we performed supplementary side-to-side comparisons for CMJ and bilateral hopping, where bilateral data were collected (see Supplementary). Side-to-side comparisons showed statistically detectable between-limb differences in some variables, but they were generally smaller than between-group differences. Peak side-to-side differences were ~1-2° for most THA hip angles, ~2-5° for TKA knee angles, and up to ~0.20 Nm/kg for joint moments. In contrast, the corresponding between-group differences reached ~18° for THA hip angles, ~30° for TKA knee angles, and ~2.3Nm/kg for joint moments. These comparisons suggest that the between-group alterations findings are unlikely to be explained solely by limb asymmetry. However, given that bilateral comparisons were not undertaken for unilateral tasks, it remains possible that side-to-side asymmetries may have contributed to some task-specific findings, particularly during unilateral tasks.

Gait alterations have a significant influence on joint contact force magnitude and direction (Foucher et al., 2009; Wesseling et al., 2016), which in turn influences implant wear (Foucher et al., 2009). A previous study reported a ~1000N increase in hip contact force (HCF) when peak extensor moment increased by ~70Nm (Foucher et al., 2009). In the present study, people with

THA performed running, CMJ, and hopping with up to 1.19 Nm/kg (approximately 83 Nm for a 70 kg person) greater peak hip extensor moment than controls. While this magnitude of difference is mechanically meaningful and consistent with factors known to influence HCF, the present inverse-dynamics data cannot directly quantify hip contact forces or edge-loading risk.

During running, THA participants adopted a greater adducted hip posture, with a lower hip abduction moment, compared to controls. A lower hip abduction moment could be attributed to residual deficits in hip abductor muscle strength (Ismailidis et al., 2021). Small changes in hip adduction (by 5°) have been shown to influence HCF magnitude (Wesseling et al., 2015). Another study reported that when the hip was moved from 20° abduction to 20° adduction, posterior edge loading of the hip occurred from 90° to 50° hip flexion (van Arkel et al., 2013). These findings suggest that people with THA may run using movement strategies that alter hip joint loading characteristics in a manner that has previously been associated with implant wear and edge loading mechanisms (Mellon et al., 2011; Underwood et al., 2012). Repetitive alterations in hip joint mechanics may also influence stress transfer across the implant-bone interface, which could indirectly affect pathways associated with bone remodelling, wear debris generation, osteolysis, and ultimately aseptic loosening. From a rehabilitation perspective, these findings suggest that hip abductor strength, frontal-plane control, and neuromuscular strategies for managing hip adduction may warrant consideration during return-to-running progression after THA.

A greater hip extensor moment during shock absorption in running, CMJ, and hopping is consistent with previous studies on walking, which reported that hip extensor moment or power increased from pre- to post-operation after a THA (Queen et al., 2019; Zhong et al., 2025). Another study reported greater peak hip power generation and absorption in high-functioning patients with THA compared to controls (Lunn et al., 2019). Our findings may be less likely attributed to the typical distal-to-proximal (i.e. less ankle, greater hip) shift in muscle function during age associated with ageing (Kulmala et al., 2014; Liew et al., 2025). Although residual confounding remains possible, both age and task intensity were statistically controlled, and the concurrent increases in ankle plantarflexor and hip extensor moments do not support a simple age-related distal-to-proximal redistribution of lower-limb function. However, a greater hip extensor moment could be in compensation for a reduction in knee extensor moment in people with THA (Wada et al., 2025). This suggests that rehabilitation of the quadriceps group may be required to reduce the reliance of the hip extensors.

Presently, participants with TKA or UKA exhibited reduced knee extensor moment, reduced knee abduction moment (i.e. external knee adduction moment), and/or reduced axial rotation and moments. These patterns may reflect protective unloading strategies. However, lower moments should be interpreted as indirect rather than direct evidence of reduced implant contact loading or wear. Implant loading is influenced by numerous factors beyond joint moments, including muscle co-contraction, contact location, and implant alignment, which were not quantified presently. Nevertheless, the present findings are consistent with previous literature reporting lower knee extensor moments in people with TKA during running (Harvey et al., 2024) and downslope walking (Wen et al., 2022). Previous works have demonstrated that the knee extensor and abduction moment explained 85% of the variance of medial KCF (Manal et al., 2015; Walter et al., 2010). A previous study reported that a 25% increase in KCF resulted in an approximately 0.5mm^3 increase in knee volumetric wear (Mell et al., 2020). Greater knee axial rotation range has been associated with increased implant wear in simulator studies (Johnson et al., 2001; McEwen et al., 2005). However, greater surgical satisfaction has been associated with greater knee axial rotation range (Hodge et al., 2024). The present findings suggest that movement strategies after TKA and UKA must balance competing mechanical objectives. Reductions in joint loading and rotational excursion may potentially reduce implant wear, but may also limit the restoration of physiological knee function.

The present study has several limitations. First, the sample size was small, particularly for the TKA and UKA groups, precluding increasing the influence of individual variability. Second, we did not recruit age-matched healthy controls because this project was conducted as part of a funded programme focused on understanding how physical activities affect implant health. Instead, existing datasets were used for comparison, whilst statistically controlling for age and performance-related confounders. Third, contralateral-limb analyses were not performed, and interpretation of contralateral limb biomechanics during bilateral tasks should be made cautiously because the contralateral osteoarthritis status was unknown. Fourth, caution should be taken when interpreting non-sagittal plane kinematics and kinetics derived from marker-based motion capture due to marker-placement error and soft tissue artefact. Finally, formal residual diagnostic tests indicated statistically detectable departures from the expected residual distribution, so findings should be interpreted alongside the visual diagnostics and with caution given the small sample sizes.

Conclusions

The long-term implications of altered biomechanics after joint arthroplasty are unlikely to be explained by isolated changes in joint angles or moments. The present findings suggest that some biomechanical adaptations during high-impact activities may involve trade-offs between reducing implant loading and preserving physiological joint function. The kinematic and kinetic waveforms reported in this study may provide clinically relevant inputs for future implant wear simulations to determine how these interacting mechanisms collectively influence implant stress, contact mechanics, and long-term implant durability during physically demanding activities.

Ethics approval and consent to participate

All participants provided written informed consent, and the study received approval from the Health Research Authority Research Ethics Committee (IRAS 327418).

Competing interest

The authors have no competing interests to declare.

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Authors' contributions

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Figure 1

Time-varying joint angle waveforms of the pairwise difference between people with Total Hip Arthroplasty, relative to controls during (a-c) running, (d-f) countermovement jumps, (g-i) unilateral hopping, (j-l) bilateral hopping, and (m-o) change of direction 45°. Lines reflect the point estimate difference, whilst error clouds reflect 95% confidence intervals. Blue error clouds indicate statistically significant differences (i.e. non-zero cross of 95% confidence intervals). Red error clouds indicate non-significant differences.

Figure 2

Time-varying joint moment waveforms of the pairwise difference between people with Total Hip Arthroplasty, relative to controls during (a-c) running, (d-f) countermovement jumps, (g-i) unilateral hopping, (j-l) bilateral hopping, and (m-o) change of direction 45°. Lines reflect the point estimate difference, whilst error clouds reflect 95% confidence intervals. Blue error clouds indicate statistically significant differences (i.e. non-zero cross of 95% confidence intervals). Red error clouds indicate non-significant differences.

Figure 3

Time-varying joint angle waveforms of the pairwise difference between people with Total Knee Arthroplasty, relative to controls during (a-c) running, (d-f) countermovement jumps, (g-i) unilateral hopping, (j-l) bilateral hopping, and (m-o) change of direction 45°. Lines reflect the point estimate difference, whilst error clouds reflect 95% confidence intervals. Blue error clouds indicate statistically significant differences (i.e. non-zero cross of 95% confidence intervals). Red error clouds indicate non-significant differences.

Figure 4

Time-varying joint moment waveforms of the pairwise difference between people with Total Knee Arthroplasty, relative to controls during (a-c) running, (d-f) countermovement jumps, (g-i) unilateral hopping, (j-l) bilateral hopping, and (m-o) change of direction 45°. Lines reflect the point estimate difference, whilst error clouds reflect 95% confidence intervals. Blue error clouds indicate statistically significant differences (i.e. non-zero cross of 95% confidence intervals). Red error clouds indicate non-significant differences.

Figure 5

Time-varying joint angle waveforms of the pairwise difference between people with Unicompartmental Knee Arthroplasty, relative to controls during (a-c) running, (d-f) countermovement jumps, (g-i) unilateral hopping, (j-l) bilateral hopping, and (m-o) change of direction 45°. Lines reflect the point estimate difference, whilst error clouds reflect 95% confidence intervals. Blue error clouds indicate statistically significant differences (i.e. non-zero cross of 95% confidence intervals). Red error clouds indicate non-significant differences.

Figure 6

Time-varying joint moment waveforms of the pairwise difference between people with Unicompartmental Knee Arthroplasty, relative to controls during (a-c) running, (d-f) countermovement jumps, (g-i) unilateral hopping, (j-l) bilateral hopping, and (m-o) change of direction 45°. Lines reflect the point estimate difference, whilst error clouds reflect 95% confidence intervals. Blue error clouds indicate statistically significant differences (i.e. non-zero cross of 95% confidence intervals). Red error clouds indicate non-significant differences.

Table 1. Demographic characteristics of participants with a joint arthroplasty

Characteristic	THA N = 11[1]	TKA N = 4[1]	UKA N = 3[1]
Age (years)	55.9 (9.8)	63.7 (4.8)	65.3 (2.5)
Sex			
Female	6 / 11 (55%)	3 / 4 (75%)	0 / 3 (0%)
Male	5 / 11 (45%)	1 / 4 (25%)	3 / 3 (100%)
Height (m)	1.7 (0.1)	1.7 (0.1)	1.8 (0.1)
Mass (kg)	68.9 (10.7)	70.9 (14.4)	102.6 (25.7)
Tested (most recently operated) side			
Left	5 / 11 (45%)	3 / 4 (75%)	1 / 3 (33%)
Right	6 / 11 (55%)	1 / 4 (25%)	2 / 3 (67%)
Contralateral joint arthroplasty	2 / 11 (18%)	3 / 4 (75%)	0 / 3 (0%)
Education			
College or university	4 / 11 (36%)	1 / 4 (25%)	0 / 3 (0%)
Higher or secondary or further education (A-levels, BTEC, etc.)	1 / 11 (9.1%)	0 / 4 (0%)	0 / 3 (0%)
Post-graduate degree	6 / 11 (55%)	3 / 4 (75%)	2 / 3 (67%)
Secondary school up to 16 years	0 / 11 (0%)	0 / 4 (0%)	1 / 3 (33%)

Work			
Full-time	7 / 11 (64%)	0 / 4 (0%)	1 / 3 (33%)
Not working	2 / 11 (18%)	4 / 4 (100%)	1 / 3 (33%)
Part-time	2 / 11 (18%)	0 / 4 (0%)	1 / 3 (33%)
Oxford (0-48)	47.2 (1.3)	46.5 (2.4)	45.0 (4.4)
K/HOOS Symptom (0-100)	96.4 (5.5)	92.0 (6.8)	97.6 (4.1)
K/HOOS Pain (0-100)	97.7 (4.7)	95.1 (4.7)	96.3 (6.4)
K/HOOS ADL (0-100)	99.2 (1.5)	98.5 (2.1)	96.1 (6.8)
K/HOOS Sports (0-100)	97.7 (4.2)	88.8 (7.5)	95.0 (8.7)
K/HOOS QOL (0-100)	88.1 (12.6)	90.6 (8.1)	95.8 (7.2)
HAAS (0-18)	17.1 (1.5)	14.3 (1.0)	13.7 (4.2)
Main Sport			
Beach Volleyball	1 / 11 (9.1%)	0 / 4 (0%)	0 / 3 (0%)
Dance	0 / 11 (0%)	1 / 4 (25%)	0 / 3 (0%)
Dog Agility	0 / 11 (0%)	1 / 4 (25%)	0 / 3 (0%)
Hockey/Pickle Ball/Hickes	0 / 11 (0%)	1 / 4 (25%)	0 / 3 (0%)
Run	10 / 11 (91%)	1 / 4 (25%)	1 / 3 (33%)

Tennis	0 / 11 (0%)	0 / 4 (0%)	2 / 3 (67%)
Competitive level of main sport			
Both recreational and competitive	3 / 11 (27%)	0 / 4 (0%)	2 / 3 (67%)
Competitive	1 / 11 (9.1%)	1 / 4 (25%)	0 / 3 (0%)
Recreational	7 / 11 (64%)	3 / 4 (75%)	1 / 3 (33%)
Experience (years) in main sport			
1 to <3	1 / 11 (9.1%)	0 / 4 (0%)	0 / 3 (0%)
10 or more	9 / 11 (82%)	4 / 4 (100%)	2 / 3 (67%)
5 to <10	1 / 11 (9.1%)	0 / 4 (0%)	1 / 3 (33%)
Weekly training frequency in main sport			
1-2 times per week	5 / 11 (45%)	2 / 4 (50%)	1 / 3 (33%)
3-4 times per week	6 / 11 (55%)	2 / 4 (50%)	2 / 3 (67%)

[1]Mean (SD); n / N (%)

Table 2. Task intensities of the five motor tasks

Intensity	Healthy	THA	TKA	UKA	P value
Running speed (m/s)	3.11 (0.51)	2.88 (0.46)	2.76 (0.28)	2.4 (0.41)	0.049
CMJ height (m)	0.33 (0.09)	0.29 (0.05)	0.2 (0.02)	0.23 (0.02)	
Unilateral hopping stance duration (s)	0.27 (0.02)	0.3 (0.02)	0.31 (0.02)	0.35 (0.03)	<0.001
Bilateral hopping stance duration (s)	0.22 (0.03)	0.24 (0.04)	0.27 (0.01)	0.29 (0.03)	<0.001
COD45 – approach speed (m/s)	4.21 (0.35)	2.68 (0.36)	2.68 (0.42)	2.33 (0.49)	<0.001
Abbreviations: CMJ – countermovement jump; COD45 – change of direction 45°; THA- total hip arthroplasty; TKA – total knee arthroplasty; UKA – unicompartmental knee arthroplasty.					