

Prevalence, incidence, and progression of hip osteoarthritis in a young military population: The ADVANCE cohort study

F.C.E. Watson^{a,*}, O. O'Sullivan^{b,c}, A. Bennett^{a,b}, R. Agricola^d, S. Schofield^a, D. Hanff^e, C. Boos^{a,f}, P. Cullinan^g, N. Fear^h, H. Kempⁱ, A.M.J. Bull^a

^a Bioengineering, Faculty of Engineering, Imperial College London, London, UK

^b Academic Department of Military Rehabilitation, Defence Military Rehabilitation Centre, Stanford Hall, UK

^c University of Nottingham, Nottingham, UK

^d Orthopaedics and Sports Medicine, Erasmus University Rotterdam, Rotterdam, the Netherlands

^e Radiology & Nuclear Medicine, Erasmus University Rotterdam, Rotterdam, the Netherlands

^f Faculty of Health and Social Sciences, Bournemouth University, UK

^g National Heart and Lung Institute, Faculty of Medicine, Imperial College London, London, UK

^h King's Centre for Military Research, King's College London, London, UK

ⁱ Department of Surgery and Cancer, Imperial College London, London, UK

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ABSTRACT

Objective: Prevalence of hip osteoarthritis (OA) is rarely reported in young populations (e.g., military). We will report the prevalence of hip OA in a young military cohort and investigate the relationship between injury and progression/incidence.

Design: ADVANCE is a prospective cohort study comparing physical and psychosocial outcomes in 1145 men who served in Afghanistan including 579 men with combat injury (Exposed) who were frequency-matched to 566 controls (Unexposed). The Exposed group was sub-divided into hip injured (Exp-H), lower limb amputation (Exp-A) and other (Exp-NA). Kellgren-Lawrence (KL) scores of pelvic radiographs and Non-Arthritic Hip Score (NAHS) questionnaires were collected across two waves (Baseline and Follow-up). Prevalence at Baseline (KL ≥ 2), progression (KL ≥ 1 at Baseline, KL ≥ 2 at Follow-up) and incidence (KLO at Baseline, KL ≥ 2 at Follow-up) at Follow-up were reported and compared between groups for KL and NAHS.

Results: Baseline prevalence of radiographic hip OA was 8.5 % and 4.4 % in the Exposed and Unexposed groups, respectively. Exp-A and Exp-H groups had 3.88 (95%CI:2.27–6.63) and 7.18 (95%CI:3.44–14.98) times increased risk for radiographic hip OA than Unexposed. Exp-A and Exp-H had a 2.15 (95%CI:1.22–3.80) and 3.28 (95%CI:1.42–7.59) times increased radiographic progression risk, compared to Unexposed. Risk of NAHS Progression and Incidence were not significantly different between groups.

Conclusion: Radiographic hip OA prevalence is higher in a young military population than in a similarly aged general population. Combat injury alone may not increase hip OA prevalence; but hip and lower limb loss injuries do. Progression risk is highest in those with hip or limb loss injuries.

1. Introduction

Globally, the prevalence of radiographic hip osteoarthritis (OA) has been reported between 1.0 % and 45.0 %, and between 1.9 % and 23.0 % in Europe [1,2]. The range of these estimates are wide due to definition of radiographic hip OA, age, and geographic variance. Often these

populations are at least middle-aged, but some studies report age-disaggregated data from younger adults, finding a prevalence of 0.4–1.4 % in men <45-years old [3,4]. As well as age [5], other factors can increase risk of hip OA such as non-white ethnicity [5], obesity [6], female sex [5,7], genetics [8], hip morphology such as cam, pincer or dysplasia [9], high bone density [10], any prior musculoskeletal injury

* Corresponding author. Imperial College London, 5th floor, Sir Michael Uren Building, 86 Wood Lane, London, W12 0BZ, UK.

E-mail addresses: f.watson@imperial.ac.uk (F.C.E. Watson), oliver.o'sullivan@nhs.net (O. O'Sullivan), alexander.bennett485@mod.gov.uk (A. Bennett), r.agricola@erasmusmc.nl (R. Agricola), s.schofield@imperial.ac.uk (S. Schofield), d.hanff@erasmusmc.nl (D. Hanff), christopher.boos@uhd.nhs.uk (C. Boos), tpaulcullinan@gmail.com (P. Cullinan), nicola.t.fear@kcl.ac.uk (N. Fear), h.kemp@imperial.ac.uk (H. Kemp), a.bull@imperial.ac.uk (A.M.J. Bull).

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and prior hip injury in particular [11,12], and high impact occupation [13,14].

Military personnel, and other active workers such as firefighters, are thought to be at a higher risk of hip OA because their occupation necessitates heavy, repetitive load bearing at high intensities [13–16]. Incidence rate ratios for military personnel are 1.26–2.01 times higher than for the general population aged 20–39 [16]. A study of hip OA in men in the US military reported incidence of 32 per 100,000 person-years [17], in comparison to incidence of 88 per 100,000 person-years in men in the general population [18]. However, the general population was skewed a lot younger. Where age categories overlapped, men aged 20–39 in the military had an incidence of 10–52 per 100,000 person-years and men aged 20–39 in the general population had an incidence of 0–8 per 100,000 person-years.

Military service increases the likelihood of musculoskeletal injury that can result in post-traumatic OA (PTOA) [19]. PTOA is less common in the hip than in the knee or ankle, accounting for 1.6 % of total hip OA in the general population [20]. Regardless, significant musculoskeletal injury of any joint is associated with a fivefold increased odds for hip OA [11]. Despite this, little is known about the risks for PTOA in the hip, with acetabular fractures, hip dislocations and femoral fractures thought to contribute [21]. The ADVANCE study found a twofold increased odds for radiographic knee OA in those who sustained any combat trauma a median of 8-years prior, increasing to a fourfold increased odds in those who sustained lower limb loss or knee-specific injury [22]. Increased knowledge of the contribution of combat injury or joint trauma to hip PTOA could improve primary and secondary prevention efforts [23,24].

Lower limb loss was a signature combat injury in the Afghanistan war [25] and remains relevant to current conflicts [26]. Existing research on hip OA in people with lower limb loss is dated, limited, and conflicting. Physician diagnosed hip OA prevalence in a cohort of unilateral transfemoral amputees was 11 %, compared to 13.6 % in a significantly younger control group [27]. Other studies report prevalence of symptomatic hip OA in 14 % and radiographic hip OA in 23 % of the intact-side limb of people with unilateral limb loss a mean of 29-years post-amputation in an older population of World War II veterans [28,29]. A scoping review found total hip arthroplasty (likely due to OA) in people with lower limb loss occurred more frequently on the intact-side limb [30]. Better understanding of the relationship between limb loss and hip OA in people with limb loss is required, particularly the relationship between symptomatic and radiographic hip OA.

Few studies report the longitudinal progression of hip OA. The Johnston County Osteoarthritis Project found increasing prevalence for radiographic hip OA as the cohort aged from 28 % at Baseline (mean age: 61.2 ± 10.6 -years) to 53 % 27-years later (mean age: 73.5 ± 7.4 -years), but symptomatic hip OA remained stable at 30 %–36 % [31]. Analysis of the Osteoarthritis Initiative (61.1 ± 9.2 -years), Cohort Hip and Cohort Knee studies (56 ± 5 -years) found new radiographic hip OA at 4-year follow-up in 1.4–13.0 % of hips, and progression of existing radiographic hip OA in 0.0–6.2 % of hips [32].

To address the lack of radiographic hip OA prevalence data in a young military population, the unknown consequences of trauma, and the patterns of progression in such populations, this analysis will (i) report prevalence of radiographic hip OA in a UK military and veteran cohort, (ii) compare relative risk for radiographic hip OA and hip symptoms across categories of combat injury severity, and (iii) compare risk of incidence and progression of radiographic hip OA and hip symptoms in a 3-year period between combat injury groups.

2. Methods

2.1. Ethics

Approval was granted by the Ministry of Defence Research Ethics Committee (357.PPE/12). Written, informed consent was provided by all participants.

2.2. Study design and participants

ADVANCE is a longitudinal cohort study investigating the long-term physical and psychosocial outcomes of combat trauma in 1145 UK military personnel who served in Afghanistan. Detailed information on recruitment, matching, power analysis, etc. can be found in the study protocol [33]. Approximately half of the cohort (Exposed; $n = 579$) sustained combat injuries requiring aeromedical evacuation to the UK, and the other half who did not (Unexposed; $n = 566$) were frequency-matched at selection for sex, age, service (e.g., Army, Navy), rank (seniority level), role (type of job), and deployment (date active in Afghanistan) to the Exposed group. These matching criteria were chosen due to their potential influence on combat injury. Female military personnel were excluded as too few sustained combat injuries requiring aeromedical evacuation to satisfy statistical requirements [34].

The Exposed group was further sub-divided into the following groups:

- Exposed – Hip Injured (Exp-H)
- Exposed – Lower Limb Amputation (Exp-A)
- Exposed – No Lower Limb Amputation (Exp-NA)

Participants who sustained an injury affecting the hip were separated into their own group as they are known to have a higher risk of hip OA [11,12]. Participants with a hip injury and lower limb loss were included in the Exp-H group to ensure that the Exp-A group represented the effect of lower limb loss alone. Participants in the Exp-NA group had neither a hip injury nor lower limb loss injury. Contemporary medical records were searched for participants who sustained femoral or pelvic combat injuries (ICD-10 codes S32 and S72). Records were manually searched, and participants who sustained a fracture to the acetabulum, pubic rami, ischium, pubis, femoral head or femoral neck were included in Exp-H. Where further detail was necessary, contemporaneous surgical notes, electronic health records, x-rays and CT scans were manually reviewed.

2.3. Data collection

Comprehensive data collection included demographics, medical history, radiographs, and patient-reported outcome measures, as reported in detail in the protocol paper [33]. This analysis will consider Baseline (2015–2020) and Follow-up (2019–2024) data collected at the Defence Medical Rehabilitation Centre, UK at Headley Court (2015–2018) and Standford Hall (2018 onwards).

Hip injury prior to index injury/deployment that could lead to an increased risk of hip OA (e.g., acetabular fracture) was determined from self-reported medical histories and electronic health records.

For participants with lower limb loss, height was measured directly wearing prosthetics or pre-limb-loss values were recorded. Weight was measured without prostheses and adjusted depending on the level and limb/s missing [35].

2.4. Outcome measures

2.4.1. Radiographic assessment

Anterior-posterior supine pelvic radiographs were taken with hips internally rotated 15° . Each hip joint was blinded for exposure status and scored by an expert reader (RA; intra-rater kappa 0.84, inter-rater kappa: 0.77 on a random sample of 50 representative radiographs) using the Kellgren-Lawrence (KL; 0 [none] to 4 [severe]) and Osteoarthritis Research Society International atlas scoring (0 [none] to 3 [severe]) for osteophytes, sclerosis and joint space narrowing [36]. Hips with Total Hip Arthroplasty (THA) due to OA were included and treated as $> KL4$.

At a person-level, the higher KL score across right and left hip was included. For THA, this was considered their worse hip. At hip-level, left and right hips were analysed separately. Radiographic hip OA was

defined as KL ≥ 2 . Incident radiographic OA was defined as hips with KL0 at Baseline and KL ≥ 2 or THA at Follow-up. Progressive radiographic OA was defined as hips with KL ≥ 1 at Baseline and KL ≥ 2 or THA at Follow-up.

2.4.2. Non-arthritic Hip Score

The Non-arthritic Hip Score (NAHS) is a valid, internally consistent, and reproducible score designed to assess hip health in a young, active population [37]. Pain, Symptoms, Physical Function, and Participation in Activity sections are scored on a Likert scale (4 [none] to 0 [extreme]). For each hip, a total score is calculated by multiplying the sum of all the questions by 1.25, resulting in a score from 0 (worst) to 100 (best).

The Minimum Clinically Important Difference and Patient Acceptable Symptom State (PASS) for the NAHS has previously been determined as 8.7 and 81.9, respectively, following arthroscopic treatment of femoroacetabular impingement [38]. Hips with THA were excluded from NAHS analysis. At a person-level for Baseline prevalence, lowest NAHS across left and right hips was used. At a hip-level, left and right NAHSs were included separately. Incident hip symptoms were defined as hips with NAHS ≥ 81.9 at Baseline and NAHS < 81.9 at Follow-up. Progressive hip symptoms were defined as hips with < 81.9 at Baseline and a decrease of ≥ 8.7 at Follow-up.

2.4.3. Clinically relevant hip OA

Participants were considered to have clinically relevant hip OA if they indicated hip pain on a body pain chart and had an Osteoarthritis Research Society International femoral or acetabular osteophyte score ≥ 2 [36], according to American College of Rheumatology diagnosis guidelines [39]. Erythrocyte sedimentation rate was not available.

2.5. Statistical analysis

At Baseline, one Unexposed and one Exposed participant were excluded because they declined pelvic radiography or because x-ray equipment was out of service. One Unexposed participant was excluded due to non-combat transtibial limb loss following matching. One Exposed participant was excluded due to bilateral femoral head excision following combat trauma.

At Baseline, radiographic assessment was unachievable for one hip of an Exp-H participant due to right hip disarticulation acquired at time of combat injury. This participant was included in person-level analysis, but only the contralateral hip was scored. Ninety-one (8.0 %) participants included at Baseline did not attend Follow-up. At Follow-up, pelvic radiographs were unavailable for 11 participants due to equipment failure ($n = 7$), staff unavailability ($n = 3$) or participant refusal ($n = 1$). These participants were excluded to allow for complete case analysis. Multiple imputation was not used due to the small number of missing results.

Continuous variables were visually assessed for normality using histograms and Q-Q plots and reported as mean (standard deviation; SD) and median (interquartile range; IQR), as appropriate. Categorical variables were compared using Chi-squared analysis. Pre-planned subgroup comparisons were performed between Unexposed and all Exposed subgroups (Unexposed vs. Exp-NA, Unexposed vs. Exp-A, Unexposed vs. Exp-H) [40].

To assess the association between exposure and Baseline prevalence of hip OA (KL ≥ 2), a modified Poisson model with robust standard errors was used, adjusting for age and socioeconomic status (using military rank as a proxy for National Statistics socioeconomic classification) [41,42]. Relative Risk and 95 % Confidence Intervals (CI) are reported. A Poisson model was applied due to the use of Progression and Incidence 'count' data across two timepoints.

At Follow-up, to assess the association between injury (Unexposed vs. Exposed, and Unexposed vs. Exp-NA/Exp-A/Exp-H groups) and Progression and Incidence of radiographic hip OA, a mixed-effects

Poisson regression model to account for the correlation between hips was used. Models were adjusted for age, socioeconomic status and time interval between Baseline and Follow-up. Risk Ratios (RRs) and 95 % CI are reported. For Progression, group numbers were too small in Exp-H, so Exp-H and Exp-A groups were combined.

Two sensitivity analyses were carried out. Firstly, a comparison of KL score between participants with and without a valid NAHS score at Baseline was conducted. Secondly, sensitivity analysis tested for potential bias resulting from inclusion of an individual's left and right hip. Regression models were run for all hips, then separately for left and right hips, and results compared.

Data were processed in Stata SE 18.5 (StataCorpLLC; TX, USA) and an alpha of < 0.05 was used to define significance.

3. Results

Baseline data were available for 1141 participants ($n = 564$ Unexposed [49.4 %], $n = 577$ Exposed [50.6 %]). Unexposed participants were a median of 7.6-years post-matched deployment and Exposed participants were a median of 8.3-years post-index injury. Participants were a mean age of 34.1-years (SD: 5.4-years), a mean height of 179.2 cm (SD: 6.7 cm), and mass of 89.0 kg (SD: 13.3 kg). The Exposed group was split into Exp-NA ($n = 407$; 70.5 %), Exp-A ($n = 142$; 24.6 %), and Exp-H ($n = 28$; 4.9 %). The Exp-A group contained 71 (50.0 %) participants with unilateral lower limb loss and 71 (50.0 %) with bilateral lower limb loss. The Exp-H group contained 15 (53.6 %) participants with lower limb loss, of which 5 had bilateral lower limb loss. The Exp-H participant with left-sided THA sustained a left-sided acetabular fracture in combat. Demographic information is described in Table 1.

No participants sustained a hip injury prior to their index injury/deployment that may increase the risk of hip OA in the future.

3.1. Baseline radiographic hip OA - prevalence

Person-level KL scores for each participant are reported in Table 2. Overall prevalence of hip OA (KL ≥ 2) was 6.5 % ($n = 74$; 95%CI: 5.1–8.1 %). Prevalence was significantly higher in the Exposed compared to the Unexposed group ($n = 49$; 8.5 % 95%CI: 6.3–11.1 % vs. $n = 25$; 4.4 % 95%CI: 2.9–6.5 %). The Exposed group had 2.05 (95%CI: 1.31–3.22) times increased risk for KL ≥ 2 compared to the Unexposed group (Table 3).

Prevalence of hip OA was 5.2 % (95%CI: 3.2–7.8 %), 14.1 % (95%CI: 8.8–20.9 %) and 28.6 % (95%CI: 13.2–48.7 %) in the Exp-NA, Exp-A and Exp-H groups respectively. Pre-determined comparisons showed that prevalence for Exp-A and Exp-H were significantly higher than the Unexposed (both $p < 0.001$). Prevalence was not significantly different for Unexposed compared to the Exp-NA group ($p = 0.56$).

After adjustment for confounders, the Exp-A and Exp-H groups had a 3.88 (95%CI: 2.27–6.63) and 7.18 (95%CI: 3.44–14.98) times increased risk for hip OA (KL ≥ 2) compared to the Unexposed group (Table 3).

3.2. Baseline hip symptoms - prevalence

Valid person-level NAHS scores were available for 1091 (95.6 %) participants. KL scores of participants without a valid NAHS score were significantly higher than those with a valid NAHS score. Overall hip symptom prevalence was 10.4 % (95%CI: 8.7–12.4 %). Significantly more participants in the Exposed group ($n = 76$, 14.0 % 95%CI: 11.2–17.3 %) had a NAHS score below the PASS of 81.9 than the Unexposed group ($n = 38$, 6.9 % 95%CI: 4.9–9.3 %).

In the subgroup analyses, the number of participants with a NAHS below the PASS was significantly higher in the Exp-H ($n = 7$, 30.4 % 95%CI: 13.2–52.9 %) and Exp-NA groups ($n = 54$, 13.9 % 95%CI: 10.6–17.7 %) compared to Unexposed group. There was no significant

Table 1
Participant demographics for Unexposed, Exposed – No Lower Limb Amputation (Exp-NA), Exposed – Lower Limb Amputation (Exp-A), and Exposed – Hip Injured (Exp-H) at Baseline.

	Whole cohort (n = 1141)	Unexposed (n = 564)	All Exposed (n = 577)	Exp-NA (n = 407)	Exp-A (n = 142)	Exp-H (n = 28)
Age (years)	34.1 (5.4)	34.3 (5.4)	34.0 (5.3)	34.5 (5.6)	32.8 (4.6)	33.8 (4.8)
Time between injury and assessment (years; median [IQR])	8.0 (6.7–9.5)	7.6 (6.6–9.1)	8.3 (6.9–9.7)	8.6 (7.1–10.0)	7.4 (6.6–8.7)	8.5 (7–9.5)
Cause of injury						
Blast			401 (69.5)	241 (592)	136 (95.7)	24 (85.7)
Gunshot	–	–	131 (22.7)	121 (29.7)	6 (4.2)	4 (14.3)
Other			3 (0.5)	3 (0.7)	0 (0.0)	0 (0.0)
Unknown			42 (7.3)	42 (10.3)	0 (0.0)	0 (0.0)
Height (cm)	179.2 (6.7)	178.8 (6.4)	179.5 (7.0)	179.0 (6.7)	181.0 (7.4)	179.3 (7.8)
Mass ^a (kg)	89.0 (13.3)	87.8 (12.3)	90.1 (14.2)	89.5 (14.0)	91.7 (14.8)	91.5 (13.1)
BMI ^a (kg/m ²)	27.8 (3.6)	27.4 (3.4)	28.1 (3.8)	27.9 (3.7)	28.5 (4.1)	28.6 (3.3)
Race (white)	1033 (90.5)	511 (90.6)	522 (90.5)	368 (90.4)	130 (91.6)	24 (85.7)
NISS (median [IQR])	–	–	12 (5–22)	9 (4–17)	22 (14–34)	27 (17–29)
NS-SEC						
Officer rank	138 (12.1)	79 (14.0)	59 (10.2)	45 (11.1)	13 (9.2)	1 (3.6)
Senior-rank	252 (22.1)	147 (26.1)	105 (18.2)	83 (20.4)	17 (12.0)	5 (17.9)
Junior rank	751 (65.8)	338 (59.9)	413 (71.6)	279 (68.6)	112 (78.9)	22 (78.6)
Still serving in military (yes)	623 (54.6)	465 (82.5)	158 (27.4)	137 (33.7)	15 (10.6)	6 (21.4)

BMI – body mass index; NISS – new injury severity score; NS-SEC – national statistics socioeconomic classification.
Age, height, mass, and BMI are reported as mean (SD). Time between injury and assessment and NISS are reported as median [interquartile range]. The remaining variables are reported as count (percentage).
^a Mass and BMI are both adjusted for limb loss as described in Methods.

Table 2
Maximum Kellgren Lawrence (KL; 0–4) and minimum Non-Arthritic Hip Score (NAHS; 0–100) scores for each participant in Unexposed, Exposed – No Lower Limb Amputation (Exp-NA), Exposed – Lower Limb Amputation (Exp-A), and Exposed – Hip Injured (Exp-H) groups at Baseline.

Kellgren-Lawrence					
	Unexposed	Exposed	Exp-NA	Exp-A	Exp-H
<u>KL</u>					
0	460 (81.6)	443 (76.8)	335 (82.3)	92 (65.8)	15 (53.6)
1	79 (14.0)	86 (14.9)	51 (12.5)	30 (21.1)	5 (17.9)
2	21 (3.7)	39 (6.8)	19 (4.7)	16 (11.3)	4 (14.3)
3	3 (0.5)	7 (1.2)	1 (0.3)	4 (2.8)	2 (7.1)
4	1 (0.2)	2 (0.4)	1 (0.3)	0 (0.0)	1 (3.6)
THA	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (3.6)
Non-arthritic hip score					
	Unexposed	Exposed	Exp-NA	Exp-A	Exp-H
<u>NAHS; median (IQR)</u>	100 (99–100)	100 (94–100)	100 (95–100)	100 (93–100)	88 (71–100)

difference between Exp-A (n = 15, 11.7 % 95%CI: 6.7–18.6 %) and Unexposed group.

3.3. Baseline clinically relevant hip OA - prevalence

At Baseline, clinically relevant hip OA was present in 1.1 % (95%CI: 0.4–2.3 %) of Unexposed, 1.5 % (95%CI: 0.5–3.2 %) of Exp-NA, 1.4 % (95%CI: 0.2–5.0 %) of Exp-A and 14.3 % (95%CI: 4.0–32.7 %) of Exp-H participants.

Table 3
Relative risk ratios (RRs) for Kellgren-Lawrence (KL) score of ≥2 in the Unexposed and Exposed groups, and Unexposed and Exposed sub-groups: Exposed – No Lower Limb Amputation (Exp-NA), Exposed – Lower Limb Amputation (Exp-A), and Exposed – Hip Injured (Exp-H) at Baseline at the hip-level. Model 1 and 2 are adjusted for age and socioeconomic status.

Predictor Variable	Unadjusted	Adjusted Model 1		Adjusted Model 2	
	RR (95 % CI)	RR (95 % CI)	p value	RR (95 % CI)	p value
<u>Injury status</u>					
Unexposed (n = 564)	1 (ref)	1 (ref)	0.002	–	–
Exposed (n = 577)	1.91 (1.20–3.06)	2.05 (1.31–3.22)			
<u>Injury status</u>					
Unexposed (n = 564)	1 (ref)	–	–	1 (ref)	<0.001
Exp-NA (n = 407)	1.16 (0.66–2.05)			1.21 (0.69–2.11)	
Exp-A (n = 142)	3.18 (1.82–5.56)			3.88 (2.27–6.63)	
Exp-H (n = 28)	6.45 (3.20–12.98)			7.18 (3.44–14.98)	

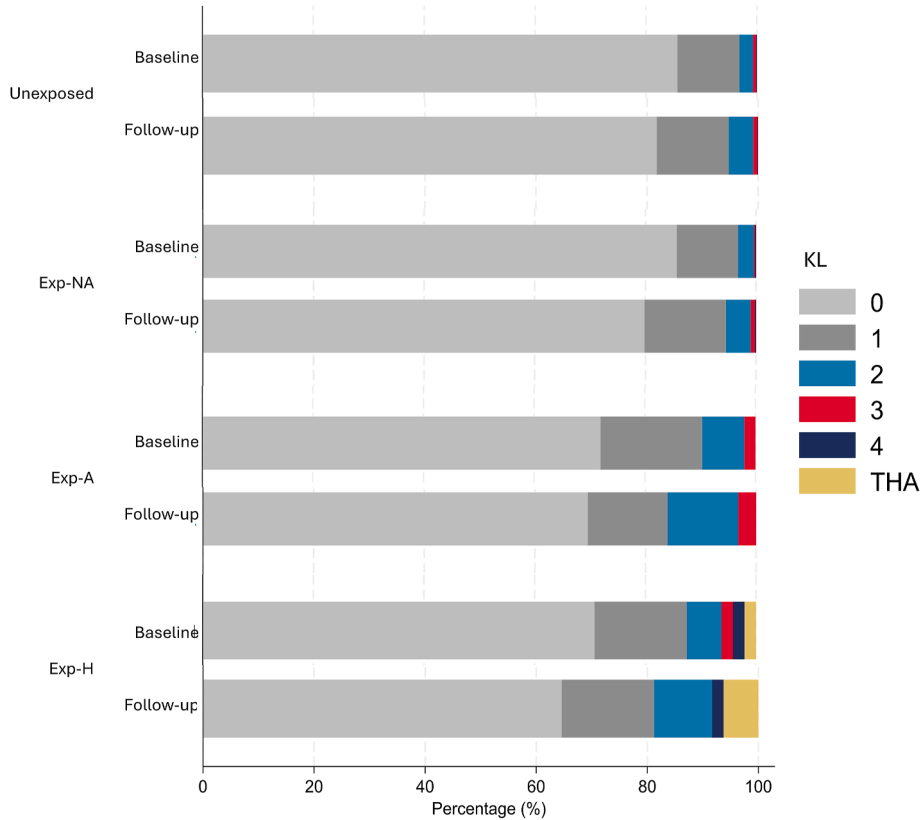


Fig. 1. Hip-level Kellgren Lawrence (KL; 0–4) scores and THA for participants with radiographs at Baseline and Follow-up in Unexposed (n = 1040 hips), Exposed – No Lower Limb Amputation (Exp-NA; n = 740 hips), Exposed – Lower Limb Amputation (Exp-A; n = 250 hips), and Exposed – Hip Injured (Exp-H; n = 48 hips) groups.

significantly higher in the Exposed group who had 2-times higher risk of radiographic hip OA. Military service is known to increase risk of hip OA [13,14,17], but the effect of combat injury has not previously been assessed. In the Exposed sub-group analysis, participants who sustained non-amputation and non-hip combat injuries (Exp-NA) were not found

to have an increased risk of radiographic hip OA compared to the Unexposed group, nor increased risk of incidence or progression in 3-years. In contrast to knee OA in the same cohort [22], these results demonstrate increased radiographic hip OA prevalence due to military service, but not necessarily from all types of combat injury. Hip and knee OA are

Table 5
Incidence rate ratios (IRRs) for Incidence and Progression of radiographic hip OA between Baseline and Follow-up in the Unexposed and Exposed groups, and Unexposed and Exposed sub-groups: Exposed – No Lower Limb Amputation (Exp-NA), Exposed – Lower Limb Amputation (Exp-A), and Exposed – Hip Injured (Exp-H) at the hip-level. Model 1 and 2 are adjusted for age, socioeconomic status and interval between Baseline and Follow-up.

Radiographic hip OA – incidence					
Predictor Variable	Unadjusted	Adjusted Model 1		Adjusted Model 2	
	IRR (95 % CI)	IRR (95 % CI)	p value	IRR (95 % CI)	p value
<u>Injury status</u>					
Unexposed (n = 891)	1 (ref)	1 (ref)	0.087	–	–
Exposed (n = 848)	1.51 (0.95–2.40)	1.50 (0.94–2.40)			
<u>Injury status</u>					
Unexposed (n = 891)	1 (ref)	–	–	1 (ref)	0.318
Exp-NA (n = 634)	1.56 (0.95–2.57)			1.53 (0.93–2.52)	
Exp-A (n = 180)	1.24 (0.59–2.59)			1.30 (0.62–2.73)	
Exp-H (n = 34)	2.10 (0.58–7.58)			2.14 (0.61–7.46)	
<u>Radiographic hip OA – progression</u>					
Predictor variable	Unadjusted	Adjusted model 1		Adjusted model 2	
	IRR (95 % CI)	IRR (95 % CI)	p value	IRR (95 % CI)	p value
<u>Injury status</u>					
Unexposed (n = 149)	1 (ref)	1 (ref)	0.039	–	–
Exposed (n = 189)	1.50 (0.89–2.55)	1.68 (1.03–2.74)			
<u>Injury status</u>					
Unexposed (n = 149)	1 (ref)	–	–	1 (ref)	0.007
Exp-NA (n = 106)	1.21 (0.64–2.28)			1.28 (0.68–2.42)	
Exp-A (n = 70) and Exp-H (n = 13)	1.88 (1.04–3.39)			2.33 (1.37–3.96)	

Table 6
Incidence rate ratios (IRRs) for Incidence and Progression of hip symptoms between Baseline and Follow-up in the Unexposed and Exposed groups, and Unexposed and Exposed sub-groups: Exposed – No Lower Limb Amputation (Exp-NA), Exposed – Lower Limb Amputation (Exp-A), and Exposed – Hip Injured (Exp-H) at the hip-level. Model 1 and 2 and adjusted for age, socioeconomic status and interval between Baseline and Follow-up.

Hip symptoms – incidence					
Predictor Variable	Unadjusted	Adjusted Model 1		Adjusted Model 2	
	IRR (95 % CI)	IRR (95 % CI)	p value	IRR (95 % CI)	p value
<u>Injury status</u>					
Unexposed (n = 954)	1 (ref)	1 (ref)	0.424	–	–
Exposed (n = 827)	1.40 (0.80–2.46)	1.25 (0.72–2.15)			
<u>Injury status</u>					
Unexposed (n = 954)	1 (ref)	–	–	1 (ref)	0.365
Exp-NA (n = 606)	1.22 (0.65–2.28)			1.07 (0.59–1.97)	
Exp-A (n = 191)	2.13 (0.95–4.81)			1.97 (0.90–4.35)	
Exp-H (n = 30)	0.87 (0.10–7.78)			0.65 (0.07–6.30)	
Hip symptoms – progression					
Predictor variable	Unadjusted	Adjusted model 1		Adjusted model 2	
	IRR (95 % CI)	IRR (95 % CI)	p value	IRR (95 % CI)	p value
<u>Injury status</u>					
Unexposed (n = 48)	1 (ref)	1 (ref)	0.507	–	–
Exposed (n = 90)	1.30 (0.43–3.95)	1.43 (0.50–4.08)			
<u>Injury status</u>					
Unexposed (n = 48)	1 (ref)	–	–	1 (ref)	0.549
Exp-NA (n = 60)	1.14 (0.35–3.73)			1.20 (0.36–4.03)	
Exp-A (n = 21) and Exp-H (n = 9)	1.60 (0.42–6.04)			1.97 (0.57–6.79)	

known to be different across prevalence, pathophysiology, biomechanics, pain profiles, and clinical presentation [43], but less is known about differences or similarities for the sequelae of combat trauma or PTOA.

Prevalence of radiographic hip OA has not been reported in people with lower limb loss sustained in recent conflicts, nor in the early years following amputation. This study found an increased prevalence (14.1 %) and 3.9-times increased risk of radiographic hip OA in those with combat-related lower limb loss (Exp-A) compared to the Unexposed group. Furthermore, this group (combined with the Exp-H group) were at an increased risk of radiographic hip OA progression over 3-years. In the general population, hip OA and hip OA progression are not thought to be longitudinally affected by biomechanical overloading, as it is in knee OA [43]. Rather, lower hip joint moments and joint contact forces have been reported in hip OA [44,45]. However, increased hip joint contact forces compared to controls have been described in military and civilian socket prosthesis users [46,47]. Over time, increased joint contact forces could lead to the increased prevalence and progression of radiographic OA seen in this study. This may incur a different progression pattern of hip OA compared to the general population. In a study on knee OA, we proposed a model of OA progression that was steeper in knees of those with lower limb loss due to ongoing biomechanical influence [48]. This study provides evidence of a similar pattern for hip OA. We recommend clinical vigilance for early signs of hip OA in people with lower limb loss, comprehensive rehabilitation, early education on hip health, and early intervention where possible.

The effect of hip injury on hip OA has already been established [12], though not in relation to combat injury. This study found 7.2-times increased risk of radiographic hip OA at Baseline and a greater risk of progression in those who sustained lower limb loss and/or a hip injury compared to the Unexposed group. This is higher than the corresponding odds for knee OA in the same cohort with a knee injury (4.1-times increased odds of radiographic knee OA and 2.2-times increased odds of progression) [22,48]. In our study, 12.5 % of those with a hip injury developed radiographic PTOA, with previous literature suggesting that trauma may be the origin of hip OA for between 1.4 % and 21 % of civilian and military populations, respectively [19,20]. However, the CI in our study were wide due to low numbers and may be further influenced by >50 % of the Exp-H group also having lower limb loss, and low progression frequency requiring combining with the Exp-A group, which

we have established increases risk of radiographic hip OA. A narrative review suggested that hip PTOA was related to the severity of the trauma [21], though we did not observe such a pattern in our small Exp-H group. Three participants in the Exp-H group had THA due to OA. Medical records noted the influence of shrapnel on the need for THA in two of these men, indicating the need for safe removal of as much shrapnel as possible for combat hip injuries in primary and early follow-up surgeries.

Overall Baseline prevalence of hip symptoms was higher than radiographic hip OA (10.4 % vs. 6.5 %). This could be an underestimation because the sensitivity analysis of KL scores in those with/without valid NAHS showed that KL scores were higher in those missing a NAHS. In the general population at similar ages hip OA symptom prevalence is reported between 1.3 % and 6.1 % between 25 and 54-years old [5,49], though different criteria/questionnaires were used. In contradiction to radiographic findings, the Exp-NA group had significantly more hip symptoms than the Unexposed group. Given the NAHS is designed to be sensitive to non-degenerative hip conditions that may affect younger, more active individuals, these could be more prevalent in this cohort. Conversely, despite increased prevalence and risk of radiographic hip OA, the Exp-A group did not have significantly different prevalence of hip symptoms from the Unexposed group. As has been previously documented in the ADVANCE cohort, we hypothesise that better mental health in the Exp-A group due to positive public perception and praise of their injuries [50], could lead to more optimistic self-reported questionnaire responses.

Whilst there was both progression and incidence of hip symptoms between Baseline and Follow-up, it was not significantly different between groups. So, despite increased progression of radiographic hip OA in the Exp-A and Exp-H groups, this was not reflected in hip symptoms. Previous literature has shown that symptoms of hip OA are quite stable over time, despite radiographic hip OA increasing over time with age [31].

4.1. Limitations

This study presents results from a two-wave analysis from an ongoing longitudinal study, so no clear patterns can be discerned. Robust statistical analysis with two-wave data did not allow for missing data, and therefore there is a small risk of survivor bias. Future longitudinal

analysis using panel data will allow for missing values. This study uses the NAHS questionnaire to describe hip symptoms using previously defined PASS and Minimum Clinically Important Difference values, which is different to other studies and is not singularly reporting OA. Despite its importance, this study does not address finer detail associated with people with limb loss. Whilst a strength and important addition to the literature, the novelty of the ADVANCE dataset may mean it has limited comparability to other PTOA cohorts due to the mechanism of injury and exclusion of female personnel. Finally, all Exposed participants in the ADVANCE study sustained complex polytrauma. They have been categorised in this study according to hip and lower limb loss injuries, but all Exposed sub-groups are likely to have sustained comorbid injuries that cannot be quantified here.

5. Conclusion

Radiographic hip OA is much higher in a young, military cohort than equivalent general population estimates. General trauma does not seem to increase the risk of hip OA, but lower limb loss and hip-related injuries do. Existing radiographic hip OA shows significantly more progression in a 3-year period in those with lower limb loss and/or hip injuries, but no difference for incidence. Further research should focus on secondary and tertiary preventative interventions for hip PTOA, especially in a military cohort and those with lower limb loss.

Author contributions

Alex Bennett, Fraje Watson, Anthony Bull, Christopher Boos, Nicola Fear, Susie Schofield, and Paul Cullinan conceived and designed the analysis. Rintje Agricola and David Hanff performed analysis of radiographs. Fraje Watson and Susie Schofield performed the analysis. Fraje Watson and Oliver O'Sullivan wrote the paper, whilst all remaining co-authors contributed to various drafts. Alex Bennett, Anthony Bull, Christopher Boos, Nicola Fear, Susie Schofield, Harriet Kemp, Rintje Agricola, and Paul Cullinan critically reviewed the study proposal, and approved the final manuscript. Fraje Watson is the guarantor.

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Declaration of competing interest

NF is the recipient of grants from the UK Ministry of Defence and the Office for Veterans' Affairs, consultation fees and support for attending meetings from Gallipoli Medical Research, a member of the Academic Advisory Board for the Office of Veterans' Affairs, a specialist advisor on the release of patient data for research for NHS England, the Director of the Forces in Mind Trust research centre, the Director of the King's Centre for Military Health Research at King's College London, and a Trustee for Help for Heroes. All other authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ocarto.2025.100675>.

References

- [1] D. Pereira, B. Peleteiro, J. Araujo, J. Branco, R.A. Santos, E. Ramos, The effect of osteoarthritis definition on prevalence and incidence estimates: a systematic review, *Osteoarthritis Cartil.* 19 (11) (2011) 1270–1285.
- [2] S. Dagenais, S. Garbedian, E.K. Wai, Systematic review of the prevalence of radiographic primary hip osteoarthritis, *Clin. Orthop. Relat. Res.* 467 (3) (2009) 623–637.
- [3] B. Goker, Radiographic osteoarthritis of the hip joint in Turkey, *Rheumatol. Int.* 21 (3) (2001) 94–96.
- [4] D. Costa, E.B. Cruz, C. Silva, H. Canhao, J. Branco, C. Nunes, et al., Factors associated with clinical and radiographic severity in people with osteoarthritis: a cross-sectional population-based study, *Front. Med.* 8 (2021) 773417.
- [5] J.M. Jordan, C.G. Helmick, J.B. Renner, G. Luta, A.D. Dragomir, J. Woodard, et al., Prevalence of hip symptoms and radiographic and symptomatic hip osteoarthritis in African Americans and Caucasians: the Johnston County Osteoarthritis Project, *J. Rheumatol.* 36 (4) (2009) 809–815.
- [6] C. Reyes, K.M. Leyland, G. Peat, C. Cooper, N.K. Arden, D. Prieto-Alhambra, Association between overweight and obesity and risk of clinically diagnosed knee, hip, and hand osteoarthritis: a population-based cohort Study, *Arthritis Rheumatol.* 68 (8) (2016) 1869–1875.
- [7] V.K. Srikanth, J.L. Fryer, G. Zhai, T.M. Winzenberg, D. Hosmer, G. Jones, A meta-analysis of sex differences prevalence, incidence and severity of osteoarthritis, *Osteoarthritis Cartil.* 13 (9) (2005) 769–781.
- [8] C. Rodriguez-Fontenla, M. Calaza, E. Evangelou, A.M. Valdes, N. Arden, F. J. Blanco, et al., Assessment of osteoarthritis candidate genes in a meta-analysis of nine genome-wide association studies, *Arthritis Rheumatol.* 66 (4) (2014) 940–949.
- [9] A.S. Nicholls, A. Kiran, T.C. Pollard, D.J. Hart, C.P. Arden, T. Spector, et al., The association between hip morphology parameters and nineteen-year risk of end-stage osteoarthritis of the hip: a nested case-control study, *Arthritis Rheum.* 63 (11) (2011) 3392–3400.
- [10] T. Funck-Brentano, M. Nethander, S. Moverare-Skrtic, P. Richette, C. Ohlsson, Causal factors for knee, hip, and hand osteoarthritis: a mendelian randomization Study in the UK biobank, *Arthritis Rheumatol.* 71 (10) (2019) 1634–1641.
- [11] R. Juhakoski, M. Heliovaara, O. Impivaara, H. Kroger, P. Knekt, H. Lauren, et al., Risk factors for the development of hip osteoarthritis: a population-based prospective study, *Rheumatology* 48 (1) (2009) 83–87.
- [12] D.J. Cooper, B.E. Scammell, M.E. Batt, D. Palmer, Factors associated with pain and osteoarthritis at the hip and knee in Great Britain's Olympians: a cross-sectional study, *Br. J. Sports Med.* 52 (17) (2018) 1101–1108.
- [13] B. Schram, R. Orr, R. Pope, E. Canetti, J. Knapik, Risk factors for development of lower limb osteoarthritis in physically demanding occupations: a narrative umbrella review, *J. Occup. Health* 62 (1) (2020) e12103.
- [14] K.L. Cameron, J.B. Driban, S.J. Svoboda, Osteoarthritis and the tactical athlete: a systematic review, *J. Athl. Train.* 51 (11) (2016) 952–961.
- [15] E. Vingard, L. Alfredsson, I. Goldie, C. Hogstedt, Occupation and osteoarthritis of the hip and knee: a register-based cohort study, *Int. J. Epidemiol.* 20 (4) (1991) 1025–1031.
- [16] K.L. Cameron, M.S. Hsiao, B.D. Owens, R. Burks, S.J. Svoboda, Incidence of physician-diagnosed osteoarthritis among active duty United States military service members, *Arthritis Rheum.* 63 (10) (2011) 2974–2982.
- [17] D.L. Scher, P.J. Belmont Jr., S. Mountcastle, B.D. Owens, The incidence of primary hip osteoarthritis in active duty US military servicemembers, *Arthritis Rheum.* 61 (4) (2009) 468–475.
- [18] S.A. Oliveria, D.T. Felson, J.I. Reed, P.A. Cirillo, A.M. Walker, Incidence of symptomatic hand, hip, and knee osteoarthritis among patients in a health maintenance organization, *Arthritis Rheum.* 38 (8) (1995) 1134–1141.
- [19] J.C. Rivera, J.C. Wenke, J.A. Buckwalter, J.R. Ficke, A.E. Johnson, Posttraumatic osteoarthritis caused by battlefield injuries: the primary source of disability in warriors, *J. Am. Acad. Orthop. Surg.* 20 (2012). Suppl 1(0 1):S64–S69.
- [20] T.D. Brown, R.C. Johnston, C.L. Saltzman, J.L. Marsh, J.A. Buckwalter, Posttraumatic osteoarthritis: a first estimate of incidence, prevalence, and burden of disease, *J. Orthop. Trauma* 20 (10) (2006) 739–744.
- [21] M.C. Castano Betancourt, C.R. Maia, M. Munhoz, C.L. Morais, E.G. Machado, A review of Risk Factors for Post-traumatic hip and knee osteoarthritis following

- musculoskeletal injuries other than anterior cruciate ligament rupture, *Orthop. Rev.* 14 (4) (2022) 38747.
- [22] F.P. Behan, A.N.B. Bennett, F.C.E. Watson, S. Schofield, E. Miller, O. O'Sullivan, et al., Osteoarthritis after major combat trauma: the Armed Services Trauma Rehabilitation Outcome Study, *Rheumatology Advances in Practice* 9 (2) (2025) rkaf033.
- [23] J.L. Whittaker, E.M. Roos, A pragmatic approach to prevent post-traumatic osteoarthritis after sport or exercise-related joint injury, *Best Pract. Res. Clin. Rheumatol.* 33 (1) (2019) 158–171.
- [24] O. O'Sullivan, Management and prevention strategies for osteoarthritis in tactical athletes, *BMJ Mil Health* (2024) e002719.
- [25] H. Chandler, K. MacLeod, J.G. Penn-Barwell, G. Severe Lower Extremity Combat Trauma Study, Extremity injuries sustained by the UK military in the Iraq and Afghanistan conflicts: 2003-2014, *Injury* 48 (7) (2017) 1439–1443.
- [26] R.A. Stevens, M.S. Baker, O.B. Zubach, M. Samotowka, Misuse of tourniquets in Ukraine may be costing more lives and limbs than they save, *Mil. Med.* 189 (11–12) (2024) 304–308.
- [27] B. Welke, E. Jakubowicz, F. Seehaus, K. Daniilidis, M. Timpner, N. Tremmer, et al., The prevalence of osteoarthritis: higher risk after transfemoral amputation?—A database analysis with 1,569 amputees and matched controls, *PLoS One* 14 (1) (2019) e0210868.
- [28] P.A. Struyf, C.M. van Heugten, M.W. Hitters, R.J. Smeets, The prevalence of osteoarthritis of the intact hip and knee among traumatic leg amputees, *Arch. Phys. Med. Rehabil.* 90 (3) (2009) 440–446.
- [29] J. Kulkarni, J. Adams, E. Thomas, A. Silman, Association between amputation, arthritis and osteopenia in British male war veterans with major lower limb amputations, *Clin. Rehabil.* 12 (4) (1998) 348–353.
- [30] T.J. Walton, A.L.D. Chatterton, V.A. Goodwin, Hip and knee replacement in lower limb amputees: a scoping review, *BMC Musculoskelet. Disord.* 25 (1) (2024) 239.
- [31] A.E. Nelson, D. Hu, L. Arbeeve, C. Alvarez, R.J. Cleveland, T.A. Schwartz, et al., Point prevalence of hip symptoms, radiographic, and symptomatic OA at five time points: the Johnston County Osteoarthritis Project, 1991-2018, *Osteoarthritis Cartil. Open* 4 (2) (2022).
- [32] Z. Salis, A. Sainsbury, Association of change in body mass index with incidence and progression of the structural defects of hip osteoarthritis: data from the osteoarthritis initiative and the cohort hip and cohort knee study, *Arthritis Care Res.* 75 (7) (2023) 1527–1537.
- [33] A.N. Bennett, D.M. Dyball, C.J. Boos, N.T. Fear, S. Schofield, A.M.J. Bull, et al., Study protocol for a prospective, longitudinal cohort study investigating the medical and psychosocial outcomes of UK combat casualties from the Afghanistan war: the ADVANCE Study, *BMJ Open* 10 (10) (2020) e037850.
- [34] Defence Mo, in: D. Statistics (Ed.), Freedom of Information Request 2015/07390, 2015.
- [35] A.H. Tzamaloukas, A. Patron, D. Malhotra, Body mass index in amputees, *JPEN - J. Parenter. Enter. Nutr.* 18 (4) (1994) 355–358.
- [36] R.D. Altman, G.E. Gold, Atlas of individual radiographic features in osteoarthritis, revised, *Osteoarthritis Cartil.* 15 (Suppl A) (2007) A1–A56.
- [37] C.P. Christensen, P.L. Althausen, M.A. Mittleman, J.A. Lee, J.C. McCarthy, The nonarthritic hip score: reliable and validated, *Clin. Orthop. Relat. Res.* (406) (2003) 75–83.
- [38] P.J. Rosinsky, C. Kyin, D.R. Maldonado, J. Shapira, M.B. Meghpara, H.K. Ankem, et al., Determining clinically meaningful thresholds for the nonarthritic hip Score in patients undergoing arthroscopy for femoroacetabular impingement syndrome, *Arthroscopy* 37 (10) (2021) 3113–3121.
- [39] R. Altman, G. Alarcon, D. Appelrouth, D. Bloch, D. Borenstein, K. Brandt, et al., The American College of Rheumatology criteria for the classification and reporting of osteoarthritis of the hip, *Arthritis Rheum.* 34 (5) (1991) 505–514.
- [40] K.J. Rothman, No adjustments are needed for multiple comparisons, *Epidemiology* 1 (1) (1990) 43–46.
- [41] S.Y. Yoong, D. Miles, P.A. McKinney, I.J. Smith, N.J. Spencer, A method of assigning socio-economic status classification to British Armed Forces personnel, *J. Roy. Army Med. Corps* 145 (3) (1999) 140–142.
- [42] Statistics OoN, SOC 2020 Volume 3: the National Statistics Socio-economic Classification (NS-SEC Rebased on the SOC 2020), 2020 [Available from: <https://www.ons.gov.uk/methodology/classificationsandstandards/standardoccupationalclassification/soc2020/soc2020volume3thenationalstatisticsocioeconomicclassificationnssecbasedonthesoc2020>].
- [43] M. Hall, M. van der Esch, R.S. Hinman, G. Peat, A. de Zwart, J.G. Quicke, et al., How does hip osteoarthritis differ from knee osteoarthritis? *Osteoarthritis Cartil.* 30 (1) (2022) 32–41.
- [44] L.E. Diamond, K. Allison, F. Dobson, M. Hall, Hip joint moments during walking in people with hip osteoarthritis: a systematic review and meta-analysis, *Osteoarthritis Cartil.* 26 (11) (2018) 1415–1424.
- [45] L.E. Diamond, H.X. Hoang, R.S. Barrett, A. Loureiro, M. Constantinou, D.G. Lloyd, et al., Individuals with mild-to-moderate hip osteoarthritis walk with lower hip joint contact forces despite higher levels of muscle co-contraction compared to healthy individuals, *Osteoarthritis Cartil.* 28 (7) (2020) 924–931.
- [46] D. Toderita, C.D. Favier, D.P. Henson, V. Vardakastani, K. Sherman, A.N. Bennett, et al., Hip joint and muscle loading for persons with bilateral transfemoral/through-knee amputations: biomechanical differences between full-length articulated and foreshortened non-articulated prostheses, *J. NeuroEng. Rehabil.* 20 (1) (2023) 169.
- [47] H.C. Davis-Wilson, C.L. Christiansen, B.M.M. Gaffney, G. Lev, E. Enabulele, C. Hoyt, et al., Changes in lower extremity joint moments one-year following osseointegration in individuals with transfemoral lower-limb amputation: a case series, *Clin. Biomech.* 104 (2023) 105948.
- [48] O'Sullivan O, Watson FCE, Bull A, Schofield S, Boos CJ, Cullinan P, et al. Influence of major trauma and lower limb loss on radiographic progression and incidence of knee osteoarthritis and pain: a comparative and predictive analysis from the ADVANCE study. *preprint* 21/5/25. Available from: <https://www.researchsquare.com/article/rs-6119632/v1>.
- [49] E.M. Badley, A. Tennant, Changing profile of joint disorders with age: findings from a postal survey of the population of Calderdale, West Yorkshire, United Kingdom, *Ann. Rheum. Dis.* 51 (3) (1992) 366–371.
- [50] D. Dyball, A.N. Bennett, S. Schofield, P. Cullinan, C.J. Boos, A.M.J. Bull, et al., Mental health outcomes of male UK military personnel deployed to Afghanistan and the role of combat injury: analysis of baseline data from the ADVANCE cohort study, *Lancet Psychiatry* 9 (7) (2022) 547–554.