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RESEARCH ARTICLE

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Risk of post-traumatic knee osteoarthritis after knee injury in military service members

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Abstract

Purpose: The aims of the present study were: (a) to identify the incidence of osteoarthritis (OA) after a traumatic knee injury; (b) identify the risk of post-traumatic osteoarthritis (PTOA) based on the type of injury; and (c) identify the time from injury to OA diagnosis.

Patients and methods: The Expeditionary Medical Encounter Database, containing healthcare utilization for all deployment injuries sustained by military service members, was queried for traumatic knee injuries between 2001 and 2016. Subsequent diagnosis of knee OA was identified, defined as PTOA. Time to knee PTOA diagnosis was determined and logistic regression was used to obtain odds ratios (ORs) (95% confidence interval [CI]) between knee injury type and development of PTOA.

Results: A total of 345 (9.57%) of the 3,605 subjects were diagnosed with PTOA. The median time to diagnosis was 4.10 years. Four primary diagnoses remained significantly associated with PTOA after adjusting for age and injury severity score: fracture (adjusted OR [aOR] = 1.36; 95% CI 1.02, 1.82), sprain (aOR = 1.59; 95% CI 1.23, 2.06), dislocation (aOR = 3.70; 95% CI 2.09, 6.55) and derangement (aOR = 2.38; 95% CI 1.33, 4.28). Subjects were significantly less likely to develop PTOA after a soft-tissue injury (aOR = 0.44; 95% CI 0.41, 0.75).

Conclusions: A substantial number of individuals with a traumatic knee injury developed early PTOA (9.6%). Certain knee injuries have a greater association with PTOA. Future studies should implement longer surveillance periods and identify other healthcare variables associated with the risk of developing PTOA, to include appropriate and timely interventions.

KEYWORDS

post-traumatic osteoarthritis, tactical athlete, knee injury, trauma

1 | INTRODUCTION

Osteoarthritis (OA) occurs when there is breakdown or damage to the articular cartilage and surrounding tissues (Haviv, Bronak, & Thein, 2013; Litwic, Edwards, Dennison, & Cooper, 2013; Zhang & Jordan, 2010). The development of OA as a direct or indirect result of joint injury is defined as post-traumatic osteoarthritis (PTOA) (Anderson et al., 2011) and is best considered as a syndrome of joint degeneration, dysfunction and pain that develops after joint injuries. Unlike idiopathic OA (IOA), which primarily affects people older than 60 years and involves degenerative changes that are frequently associated with joint aging, PTOA causes pain and disability for young and middle-aged adults as well as the elderly. This is especially true for individuals with high-risk occupations or sports-related activities that

increase the risk of joint-related injury (Buckwalter & Brown, 2004). Within the general population, a substantial percentage (~12%) of all cases associated with OA can be traced to an initial event involving joint trauma (Brown, Johnston, Saltzman, Marsh, & Buckwalter, 2006). It has been estimated that the number of patients in the United States with disabling PTOA of the hip, knee or ankle approaches 6 million and accounts for approximately 3 billion dollars in US expenditures (Brown et al., 2006).

As not all patients develop OA after a traumatic knee injury, or at least not any faster than non-injured controls, the factors that expedite the onset of PTOA are not fully known. Research has shown that joint injuries involving direct and indirect impact loading; meniscal, ligament and joint capsule tears; and intra-articular fractures increase the risk of a rapid, progressive joint degeneration that causes PTOA (Martin, Brown, Heiner, & Buckwalter, 2004). Traumatic injuries may occur from sports or accidents, but most frequently involve injury during occupational demands (Aluoch & Wao, 2009). Within the military, combat-related musculoskeletal injuries are forms of occupationally derived trauma often leading to the development of PTOA. Degenerative arthritis is the most common unfitting condition for battlefield-injured service members who are medically discharged from military service (Davila, Swiontkowski, & Andersen, 2016; Rivera, Wenke, Buckwalter, Ficke, & Johnson, 2012). A diagnosis of OA is associated with a higher incidence of disability and medical discharge from military service than with any other condition (Rivera et al., 2012). Reports suggest that some cases of PTOA can begin to be identified within 2–5 years after a traumatic injury (Haviv et al., 2013), primarily after certain intra-articular fractures (Anderson et al., 2011), and cartilage degeneration is documented in the majority of individuals with confirmed cartilage injury within 5 years (Johnson, Urban, Caborn, Vanarthos, & Carlson, 1998). However, this has not been investigated in a military population. A better understanding of the relationship between initial injury and PTOA onset is necessary, especially if targets for appropriate preventative intervention are to be determined. Identifying the onset of OA after traumatic injury is challenging because surveillance is needed in systems that can track comprehensive health services utilization for patients over long periods. The Military Health System (MHS) is one of very few large closed systems that exist in the United States, with very little missing data (Rhon, Clewley, Young, Sissel, & Cook, 2018).

The purpose of the present study was to identify the prevalence of OA after a traumatic knee injury, the average time to diagnosis, and variables that differentiate those with and without an early PTOA diagnosis. The primary hypothesis was that injury type would be associated with a PTOA diagnosis.

2 | METHODS

2.1 | Study design & setting

The study had an observational retrospective design, involving a cohort of deployed military service members in the US MHS.

2.2 | Participants

The study population consisted of US service members who sustained a deployment-related traumatic knee injury between 1 January 2001 and 1 October 2016. Service members who were killed in action or died of wounds, in relation to the inclusion episode, were excluded, as well as service members who sustained a lower extremity amputation. If an individual had multiple knee injury events, only the first injury event was included. In addition, service members with a traumatic knee injury diagnosis in the 12 months prior to the study injury event were excluded. Finally, records with missing identifiers, missing injury dates or missing injury severity score (ISS)—an overall measure of injury severity composed of the three most injured body regions, with a range of 0 to 75 (Baker, O'Neill, Haddon, & Long, 1974)—were excluded.

2.3 | Study variables

The primary study variable of interest was a diagnosis code rendered by a licensed medical provider for an acute or traumatic knee injury, as identified by the International Classification of Diseases, 9th Revision, Clinical Modifications (ICD-9-CM). These codes were further separated into six categories: fracture, joint sprain, joint dislocation, soft-tissue injury, joint derangement and other. In addition, variables containing information about the injury event and patient demographics at the time of injury were also included, such as age, sex, casualty status (battle or nonbattle injury), branch of service, pay grade, ISS and mechanism of injury.

2.4 | Outcome variables

The diagnosis of knee OA was determined by identification of medical visits occurring after the traumatic knee injury, with a documented ICD-9-CM code of 715.16, 715.26, 715.36 or 715.96, or an ICD-10-CM code of M17.XX (knee OA).

2.5 | Reporting guidelines

The REporting of studies Conducted using Observational Routinely collected health-Data (RECORD) statement (Benchimol et al., 2015), an extension of the Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) (Langan, Cook, & Benchimol, 2016) checklist, was used to guide reporting of the study. Ethical approval was granted by the Brooke Army Medical Center Institutional Review Board.

2.6 | Data sources

Data regarding the inclusion injury event and subject demographics at the time of injury were derived from the Expeditionary Medical Encounter Database, which captures and tracks healthcare utilization for all deployment injuries sustained by US military service members in support of a foreign contingency. Additional data regarding possible previous knee injury diagnoses, as well as outcome data, were extracted from the MHS Data Repository (MDR). The MDR is the

centralized data repository that captures, archives, validates, integrates and distributes Defense Health Agency corporate healthcare data worldwide (Military Health System Data Repository, n.d.). The MDR includes person-level data for all outpatient and inpatient medical visits, both in military hospitals and in the civilian network, as well as imaging procedures and pharmacy data.

2.7 | Statistical approach

Group differences between comparison groups and statistical significance were identified utilizing t-tests for age and chi-squared tests for all other categorical variables. Significance was determined at $p < 0.05$. Follow-up was obtained on all individuals included in the cohort, and time to knee OA diagnosis was documented for those who were identified with the condition present. To assess the relationship between knee injury type and the development of PTOA, logistic regression was used to obtain crude and adjusted odds ratios (aORs) and 95% confidence intervals (CIs). Stepwise regression was used to determine which covariates to include in the final model, resulting in the inclusion of age, treated as a continuous variable, and ISS, treated categorically.

3 | RESULTS

Of the 3,605 unique individuals who met the inclusion criteria, 345 (9.57%) were diagnosed with knee OA (Figure 1). Patients with a diagnosis of PTOA were significantly older (31.1 versus 26.0 years) and were significantly different in terms of rank, with those developing knee OA more frequently senior enlisted or officers (Table 1). There were no significant differences between branches of service, with the exception of the Marines, with a significantly smaller percentage of individuals with knee OA serving in this branch at the time of injury as compared with those who did not develop knee OA. Significant differences were seen in ISS categories, with a significantly higher percentage with moderate (32.2% versus 25.8%) and severe (13.6% versus 7.9%) ISS compared with individuals without a knee OA diagnosis. There were no significant differences between groups in regard to mechanism of injury (Table 1).

The average surveillance period for the entire cohort was 8.45 ± 3.27 years (median = 9.79 years). For those who developed knee OA, the average time to diagnosis was 4.10 years (Table 2). The average follow-up time for those who did not develop knee OA was 8.91 (±2.88) years. Four of the six knee injury categories were significantly associated with the development of knee OA (Table 3), findings which persisted even after adjustment—dislocation (aOR = 3.70; 95% CI 2.09, 6.55), derangement (aOR = 2.38; 95% CI 1.33, 4.28), sprain (aOR = 1.59; 95% CI 1.23, 2.06) and fracture (aOR = 1.36; 95% CI 1.02, 1.82). Subjects were significantly less likely to develop PTOA after a soft-tissue injury (aOR = 0.55; 95% CI 0.41, 0.75).

The most common knee injuries among those who developed knee OA were fractures (Table 4), with 57% of the sample having at least one fracture diagnosis, followed by sprains (26%) and soft-tissue injuries (9%). In those who did not develop knee OA, 48% had at least one fracture diagnosis, followed by sprains (25%) and soft-tissue injuries (23%).

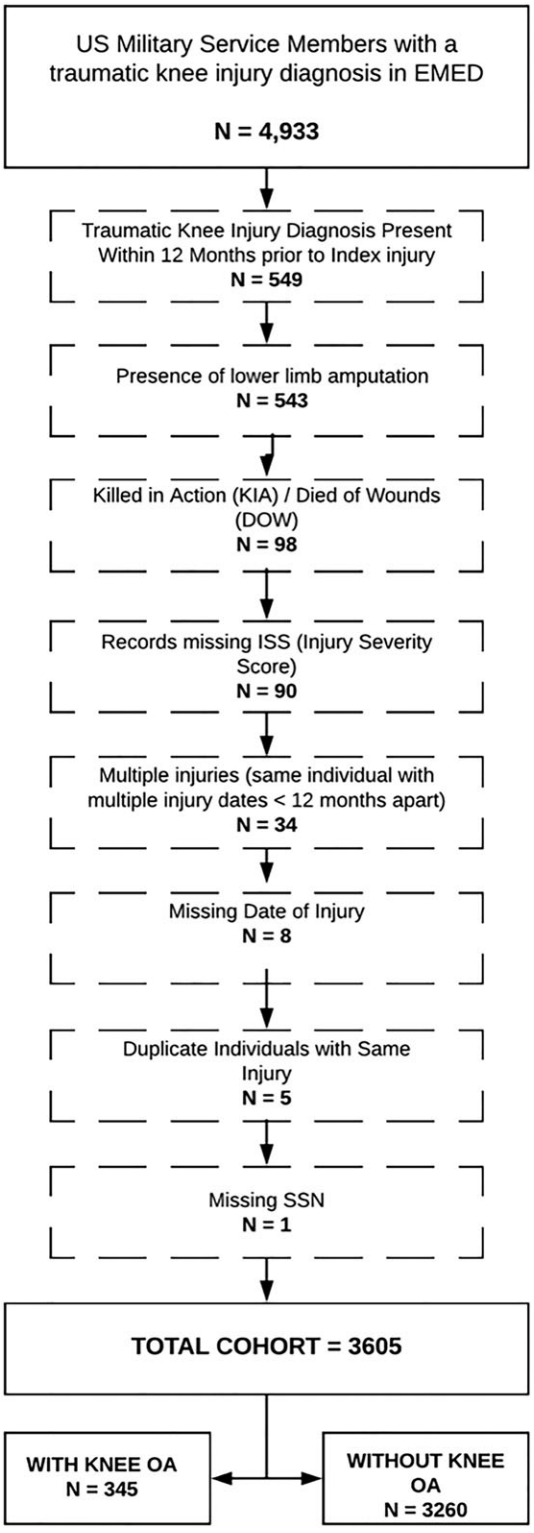

FIGURE 1 Cohort selection process. EMED: Expeditionary Medical Encounter Database; OA: osteoarthritis; SSN: social security number

4 | DISCUSSION

In this cohort of military service members sustaining a deployment-related traumatic knee injury, the injury type was significantly associated with a subsequent diagnosis of OA. Dislocations, derangements, sprains and fractures were more likely to result in a diagnosis of OA, whereas soft-tissue injuries were not. The subset of injured individuals

TABLE 1 Patient characteristics by knee osteoarthritis (OA) diagnosis

	Knee OA diagnosis present (*n* = 345)	Knee OA diagnosis absent (*n* = 3260)
Mean age in years* (SD)	31.1 (8.89)	26.0 (6.10)
Male sex	323 (93.6%)	3115 (95.5%)
Battle injury[a]	213 (61.7%)	2124 (65.2%)
Branch of service		
Army	195 (56.5%)	1695 (52.0%)
*Marine**	121 (35.1%)	1386 (42.5%)
Navy	24 (7.0%)	156 (4.8%)
Air Force	5 (1.5%)	23 (0.7%)
Rank		
*Junior (E1–E3)**	57 (16.5%)	966 (29.6%)
*Midlevel (E4–E5)**	122 (35.4%)	1462 (44.9%)
*Senior (E6–E9)**	93 (27.0%)	392 (12.0%)
*Officer (O & W)**	41 (11.9%)	169 (5.2%)
ISS		
*Mild (0–3)**	111 (32.2%)	1575 (48.3%)
*Moderate (4–8)**	111 (32.2%)	842 (25.8%)
Serious (9–15)	76 (22.0%)	584 (17.9%)
*Severe (≥16)**	47 (13.6%)	259 (7.9%)
Mechanism of injury		
Blast	168 (48.7%)	1759 (53.4%)
Gunshot wound	42 (12.2%)	307 (9.4%)
*Other**	135 (39.1%)	1194 (36.6%)

E: enlisted; ISS: injury severity score; O: officer; SD: standard deviation; W: warrant officer.

[a]As opposed to a nonbattle injury. Includes: aggravated range of motion, altercation/assault, bite/sting, blunt, building collapse, burn, complex, collateral, crush, fall, flying debris, helicopter crash, knife/sharp object, machinery or equipment, motor vehicle accident, not applicable, not documented, other, parachute drop, pedestrian, and plane crash.

*Significant difference between groups at $p < 0.05$.

N (%) unless otherwise noted.

TABLE 2 Surveillance and follow-up: the time to a diagnosis of osteoarthritis

Time to knee OA diagnosis (*n* = 345)	
Mean	**4.10 ± 3.54 years**
Median	2.99 years
Mode	0.30 years (110 days)
Range	0.0027 (1 day) to 13.57 years
Follow-up time (*n* = 3260)	
Mean	**8.91 ± 2.88 years**
Median	9.79 years
Mode	12.1 years
Range	0.20 (73 days) to 14.89 years
Surveillance Time (*n* = 3605)	
Mean	**8.45 ± 3.27 years**
Median	9.51 years
Mode	12.1 years
Range	0.0027 (1 day) to 14.89 years

OA: osteoarthritis.

TABLE 3 Odds ratio for association between type of knee injury and knee osteoarthritis diagnosis

	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Fracture*	1.69 (1.35, 2.11)	1.36 (1.02, 1.82)
Sprain*	1.33 (1.06, 1.68)	1.59 (1.23, 2.06)
Soft tissue*	0.44 (0.33, 0.59)	0.55 (0.41, 0.75)
Dislocation*	3.27 (1.90, 5.64)	3.70 (2.09, 6.55)
Derangement*	3.95 (2.33, 6.72)	2.38 (1.33, 4.28)
Other	0.38 (0.09, 1.58)	0.40 (0.09, 1.68)

CI: confidence interval;

OR: odds ratio.

*$p < 0.05$. Crude and adjusted for age and injury severity scale (categorically, referent group = "Mild").

TABLE 4 Total number of traumatic knee injuries, by category

Knee injury category[a]	Knee OA present (*n* = 345)	Knee OA absent (*n* = 3260)
Fracture	373 (57%)	2314 (48%)
Sprain	171 (26%)	1218 (25%)
Soft tissue	61 (9%)	1082 (23%)
Dislocation	21 (3%)	62 (1%)
Derangement	21 (3%)	53 (1%)
Other	2 (<1%)	51 (1%)
TOTAL	**649**	**4780**

OA: osteoarthritis.

[a]Patients can have multiple injuries and be coded into more than one category.

who went on to develop PTOA represented 9.57% of the total cohort, and the median time to diagnosis of OA was 4.10 years. Although these results were limited to observational data and had some limitations, they help to serve as informed estimates for the timing of diagnosis after traumatic injury in this population, as well as the types of injuries most likely to develop into early OA. Estimates specific to this patient population are lacking, but necessary to improve our understanding of disease progression and prevention in this setting.

The percentage of individuals sustaining a diagnosis of OA after a traumatic knee injury (9.57%) was lower in the present study than has been reported in other settings (20–60%). It is likely that if the surveillance period had been extended, the number would have been higher. OA developed in approximately 20–48% of individuals sustaining an anterior cruciate ligament (ACL) injury of the knee, but in surveillance periods beyond 10 years (Ajuied et al., 2014; Øiestad, Engebretsen, Storheim, & Risberg, 2009). A large percentage (80%) of knee injuries with magnetic resonance imaging (MRI)- or arthroscopy-confirmed cartilage injury developed cartilage degeneration within 5 years (Johnson et al., 1998). It is also possible that some cases of OA were not identified in our cohort. A diagnosis of OA can be made without radiographic evidence if other clinical findings are present (Altman et al., 1987). However, radiographic confirmation is often considered as the salient criterion for diagnosis in clinical settings, and it is possible that a patient presenting with knee pain and clinical criteria for an OA diagnosis received a different diagnostic label because the radiographs were unremarkable. Alternatively, patients may have had traumatic injuries before their time in the military or sustained a traumatic injury that was below their threshold for

seeking care (self-managed). In both of these cases, either the traumatic injury or the diagnosis of OA would not have appeared in their medical records, affecting the incidences of PTOA that we found. Finally, some may have also received care outside of the MHS, through private providers, none of which would have been captured in the MDR. However, this is likely to have been minimal, as care in the MHS would have been at no cost to the individual, but in other settings would probably have incurred out-of-pocket costs. Regardless, a review of data from the US Army Physical Evaluation Board found that arthritis was the most common condition that rendered soldiers no longer fit for military duty, and 94.4% of these cases were related to combat trauma (Rivera et al., 2012). The number of cases of OA in general, particularly of the knee and hip, are consistently higher in those with military exposure than in others (Cameron, Driban, & Svoboda, 2016). Therefore, a better understanding of the factors that affect the onset of OA after injury is of great relevance for decreasing disability in this setting.

Timing the onset of OA after traumatic knee injury is challenging for many reasons. Foremost, there are multiple criteria for the diagnosis of OA, and progression can be measured in a diverse number of ways, including radiographic, MRI, clinical, arthroscopic and histological (Madry et al., 2016). The time to onset after injury is also highly dependent on the surveillance methods used, including the sensitivity of the tools and frequency of measurement. The median time to knee OA diagnosis was 4.10 years in our cohort. Our findings are significantly lower in comparison with other populations, with reports stating that OA onset after injury occurs in as many as 20–50% of individuals within 5 years (Dirschl et al., 2004). However, the claim in the review paper most often referenced for this statistic appears to be anecdotal, and there are no data referenced to validate the claim (Kramer, Hendricks, & Wang, 2011). In tibial plafond fractures of the ankle, 70% of patients developed OA within 5–11 years after injury (Marsh et al., 2002). In a trial with an average follow-up of 14 years after ACL reconstruction, there was a threefold increase in OA compared with the healthy contralateral knee (Barenius et al., 2014). The current prevailing consensus seems to be that a typical diagnosis does not occur until 15–20 years after the precipitating injury (Riordan, Little, & Hunter, 2014). However, the exact time to diagnosis or onset of symptoms after knee injury is for the most part unknown and has been poorly investigated. Therefore, it is difficult to explain why our finding of 9.6% developing PTOA within a relatively short period (~4 years to diagnosis; ~9 years of surveillance) is so much lower than in other studies, albeit with much longer surveillance periods

There was a significant association between injury variables and the development of PTOA. Fractures were the most common injury in both groups (with and without OA), but joint dislocation was associated with the highest odds of developing PTOA (aOR = 3.70; 95% CI 2.09, 6.55), followed by joint derangement (aOR = 2.38; 95% CI 1.33, 4.28). Others have found that age, sex, rank, race and branch of service are risk factors for developing OA in the military (Cameron, Hsiao, Owens, Burks, & Svoboda, 2011; Showery et al., 2016). In our cohort, those who developed PTOA were significantly older (31.1 years versus 26.0 years) than those who did not, and of higher rank. The age-related results in prior research showed that the incidence of OA increased significantly with age (Cameron et al., 2011; Showery et al., 2016). The US Marine Corps was the only one of the four services in which significantly fewer individuals received than did not receive a diagnosis of OA. The Marine Corps tends to be the most physically demanding of all four services. As exercise and physical activity are actually beneficial for OA (Hunter & Eckstein, 2009; Uthman et al., 2013), and can potentially even slow progression (Roos & Dahlberg, 2005), it may not be surprising to see a lower incidence of OA in the Marine Corps. However, there was a significant difference in mean age ($p < 0.01$; Marines being significantly younger) and rank ($p < 0.01$; junior enlisted officers being significantly younger) between the four services, and therefore these age differences were likely to have driven the differences in OA diagnosis reported between rank and service. The greater influence of age (over the other variables) was also validated by the fact that in the adjusted model, only age and injury severity were significant predictors of OA. None of the other variables were predictive of OA, and it could be that these are less discriminative for PTOA. Women have a much lower representation in the military (~15% of the entire military population) and made up an even smaller proportion of the present sample (<7%). They were also not cleared to serve in combat roles during this entire period of surveillance, which likely comes with greater risk of traumatic injury. The limited sample size affects the conclusions that can be made regarding sex as a significant predictor of a PTOA diagnosis in women. Showery and colleagues (2016) attempted to identify PTOA diagnoses from a large military health system database, but they did not look at the relationship between OA and prior injury, and they used fewer OA diagnostic codes to screen for the disease. This makes it difficult to compare their results with ours. Our data also did do not allow for an assessment of other occupational factors. The occupations in the military are diverse, ranging from physically strenuous infantry and special operations units to administrative work (mail clerks, computer operators, and so on). Occupational demands after knee injury may be important predictors of OA progression.

Future studies should identify other variables associated with the risk of developing PTOA, particularly modifiable risk factors that could serve as the basis for intervention. These could include an assessment of healthcare utilization, such as early or adequate use of surgical stabilization or physical rehabilitation after injury. In addition, based on the biomechanical chain of the lower extremity, the development of PTOA in adjacent joints should be explored. For example, a knee injury could lead to abnormal compensatory joint biomechanics in the hip and ankle. This will be critical to understanding fully the true, holistic impact of injury on health and function (Jordan et al., 2011).

4.1 | Limitations

We identified the presence of OA based on the diagnosis provided by a medical provider, which may lack both sensitivity and specificity. However, others have stated that the use of proxy measures, with imperfect sensitivity and specificity, for the development of OA will be needed in order to make clinical trials feasible (Jordan et al., 2011).

In our cohort, the diagnosis was most likely predicated on symptoms. However, it was not possible to determine the severity of OA or the criteria used for diagnoses. Other variables that were not captured might have mediated OA progression, or also slowed down

its advance (e.g. rehabilitation or surgery after rehabilitation, military duty demands, and so on). Injury severity scores were significant differentiators of OA; however, some authors have suggested that this may not be the most valid measure of injury severity (Paffrath, Lefering, Flohé, & TraumaRegister DGU, 2014). Finally, the average surveillance period for PTOA in the present cohort was 8.45 years, and OA may have developed in some of these individuals after this period. Owing to the progressive nature of OA, it is very challenging to make this diagnosis early, as physiological changes in the joint often begin before symptom onset and, even with symptoms present, are not always captured with conventional test procedures. In general, based on these limitations, our estimate of OA incidence should be considered conservative, and the real prevalence is likely to be higher.

5 | CONCLUSION

The incidence of PTOA after knee injury found in the present study was relatively low (9.57%) compared with those referenced in the current literature. However, the surveillance period of ~9 years may have only revealed a subset of patients susceptible to early progression, and longer follow-up may have resulted in better alignment with findings from other studies and in other settings. The time to onset of symptoms has been poorly investigated, making it difficult to make meaningful comparisons.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported. The view(s) expressed herein are those of the author(s) and do not reflect the official policy or position of Brooke Army Medical Center, the US Army Medical Department, the US Army Office of the Surgeon General, the Department of the Army, the Department of the Air Force, the Department of Defense, or the US Government.

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