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The Rising Incidence of Degenerative and Posttraumatic Osteoarthritis of the Knee in the United States Military

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ABSTRACT

Background: This investigation sought to quantify incidence rates (IRs) and risk factors for primary and secondary (ie, posttraumatic) osteoarthritis (OA) of the knee in an active military population.
Methods: We performed a retrospective review of United States military active duty servicemembers with first-time diagnosis of primary (International Classification of Disease, 9th Edition code: 715.16) and secondary (International Classification of Disease, 9th Edition code: 715.26) OA of the knee between 2005 and 2014 using the Defense Medical Epidemiology Database. IRs and 95% CIs were expressed per 1000 person-years, with stratified subgroup analysis adjusted for sex, age, race, military rank, and branch of military service. Relative risk factors were evaluated using IR ratios and multiple regression analysis.
Results: A total of 21,318 cases of OA of the knee were identified among an at-risk population of 13,820,906 person-years for an overall IR of 1.54 per 1000 person-years, including 19,504 cases of primary (IR: 1.41) and 1814 cases of secondary OA (IR: 0.13). The IRs of both primary and secondary OA increased significantly from 2005 to 2014. Increasing age ($P < .0001$); black race ($P < .001$); senior military rank ($P < .0001$); and Army, Marines, and Air Force services ($P < .0001$) were significantly associated with an increased risk for knee OA.
Conclusion: This study is the first large-scale report of knee OA in a young athletic population. An increasing incidence and several risk factors for knee OA were identified, indicating a need for better preventative strategies and forecasting the increased anticipated demands for knee arthroplasty among US military servicemembers.

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Osteoarthritis (OA) is a chronic progressive disease of the articular cartilage and subchondral bone that can result in significant pain, effusion, limitations in function, and progressive disability [1]. Physician-diagnosed OA is estimated to occur in up to 22.7% of the United States adult population and 49.7% of those aged >65 years [2]. In addition, arthritis is responsible for approximately 172.1 million workdays lost every year in the United States [3]. Arthritis-associated activity limitation occurs in approximately 43.2% of those with physician-diagnosed arthritis or 22.7 million US adults [2]. Radiographic OA of the knee may range from 13.8% among those aged >26 years to 37.4% in individuals aged >60 years [4-6].

Several studies have identified patient-based risk factors for OA of the knee including increasing body mass index (BMI) [7], female gender, and history of knee injury [8,9] as well as occupational risk factors such as heavy or manual work and participation in elite sports [10]. However, patient populations are often demographically and of limited sample size, and studies are unable to distinguish between primary and posttraumatic or secondary OA (PTOA) [11,12].

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OA represents perhaps the most significant occupational burden among the US military population, and the knee is among the most commonly affected joints [13,14]. In addition, the rate of OA is significantly higher for Armed Forces servicemembers than for the general population [15]. Given the associated intense physical demands and increased prevalence of occupational trauma, this population is ideal for epidemiologic investigations into risk factors for development of both primary and secondary OA. The purposes of this study were to determine the incidence of primary and secondary OA in a homogenously active US military population and identify demographic and occupational risk factors. We hypothesized that increasing age, female gender, and proxies for increased occupational demands would correlate with risk of OA.

Methods

We performed a retrospective review of all US military active duty servicemembers with the diagnosis of primary (International Classification of Diseases 9 [ICD-9] code: 715.16) and secondary (ICD-9 code: 715.26) OA of the knee between 2005 and 2014 using the Defense Medical Epidemiology Database (DMED). Methodology for data acquisition using the DMED database has been described in detail in previous publications [16-21].

The US military is a model population to study incidence because individuals are screened for preexisting injuries and conditions before military enlistment, such as rheumatoid arthritis, seronegative arthritides, and/or other collagen vascular diseases [22]. Any individuals with evidence of preexisting joint condition or injury are carefully evaluated by a musculoskeletal specialist and are either excluded from entry into active duty service or subjected to a rigorous medical waiver review [22]. While variable by branch of service, the process and requirements for medical clearance are generically detailed in Army Regulation 40-501, which delineates ICD-9 diagnoses that would preclude candidates and active duty servicemembers from beginning or continuing military services [22].

In addition, military servicemembers are subjected to organized physical training programs and stringent fitness standards to which they must adhere to remain on active duty status. Physical fitness is formally evaluated on a semiannual basis by performance on timed push-ups, sit-ups, and an aerobic event in addition to maintenance of height and weight standards. Minimum performance guidelines for each exercise are adjusted based on age and gender. Furthermore, routine organized physical training is required in the form of aerobic exercises, weight training, tactical field exercises, and the performance of core military tasks, such as military movements with heavy fighting loads (eg, 60 to >80 lb [27 to >36 kg]). All of these activities impart significant stresses about the articular cartilage of the knee and are commensurate with definitions of "very heavy work" by the Department of Labor. Servicemembers may also be required to maintain a level of physical training exceeding these baseline standards, depending on their specific branch of service and military occupational specialty. If a military servicemember is unable to maintain these requirements, medical separation is initiated.

To determine the incidence of primary and secondary OA, we independently queried ICD-9 codes 715.16 and 715.26 for new diagnoses in both inpatient and outpatient settings among US military active duty servicemembers for each year between 2005 and 2014. Diagnostic criteria of primary and secondary OA were provider dependent and based on patient history, physical examination, and pertinent radiographic imaging. Although OA of the knee is primarily an outpatient diagnosis, including new inpatient diagnoses improved the accuracy of the incidence data collected. Data were then categorized based on sex, age, race, rank, and branch of armed forces. Race information in the DMED database is obtained from the Defense Manpower Data Center, which collects servicemembers' self-reported race from the following options: white, black, Hispanic, Alaskan Native/American Indian, Asian/Pacific Islander, and other. The DMED then groups these categories into 3 larger categories: black, white, and other. The age categories are reported as <20 years, 20-24 years, 25-29 years, 30-34 years, 35-39 years, and ≥40 years. The rank categories reported were junior enlisted (E1-E4), senior enlisted (E5-E9), junior officer (O1-O3), and senior officers (O4-O9). The military service categories were Army, Navy, Air Force, and Marines. The DMED database does not include biometric data such as height, weight, and BMI so this information was not analyzed in this study. In addition, the DMED database was also queried for the total number of servicemembers on active duty during the study time period for each of the demographic parameters. To estimate incidence, 1 exposure year was defined as 1 year that each servicemember was on active duty in the US Armed Forces.

Outcome measures were incident primary and secondary OA of the knee defined as unadjusted incidence rate (IR) per 100,000 person-years and adjusted IR ratios. Unadjusted IRs with 95% confidence intervals were calculated using standard methods for each subgroup. Multiple regression analysis was used to estimate adjusted incidence rate ratios (IRR) of primary and secondary OA of the knee per 100,000 person-years according to age, sex, rank, and branch of service with 95% confidence intervals for all values. In addition, Poisson stepwise regression analysis was used to identify interactions and relative risk between demographic subgroups for both primary and secondary OA of the knee.

Results

A total of 21,318 cases of OA of the knee were identified in an at-risk population of 13,820,906 person-years, between 2005 and 2014, with 19,504 cases of primary and 1814 cases with secondary etiologies. This corresponded to an average of 2132 incident cases per year and an overall unadjusted IR of 1.54 cases per 1000 person-years (1.41 and 0.13 cases per 1000 person-years for primary and secondary OA, respectively).

Several yearly differences in IRs for both primary and secondary OA were statistically significant and showed a trend toward increasing incidence over the course of our study (Fig. 1, Table 1). The adjusted IR of primary OA increased by 0.0198 per year ($R^2 = 0.4246$), and the adjusted IR of secondary OA of the knee increased by 0.003 per year ($R^2 = 0.7891$). The adjusted IR of primary OA of knee increased by 45% from 0.51 (95% CI, 0.48-0.55) in 2005 to 0.74 (95% CI, 0.69-0.79) in 2014. The adjusted IR of secondary OA of the

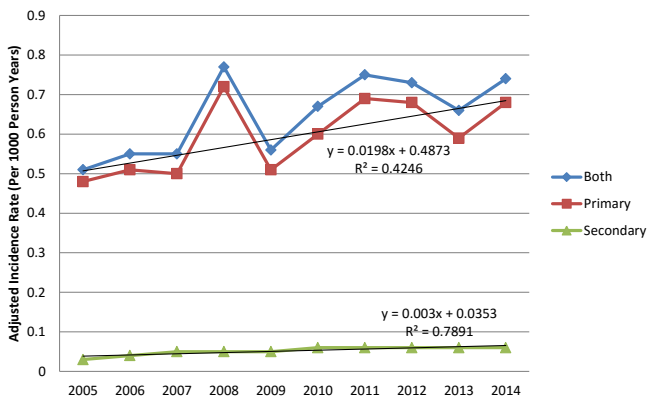

Fig. 1. Adjusted incidence rate of osteoarthritis of the knee by year.

Table 1
Incidence of Primary and Secondary OA of the Knee by Year.

Year	Person-Years	Total No. of Knee OA Dx	Unadjusted Incidence Rate[a] (95% CI)	Adjusted Incidence Rate[b] (95% CI)	No. of 1° Knee OA Dx	Unadjusted Incidence Rate[a] (95% CI)	Adjusted Incidence Rate[b] (95% CI)	No. of 2° Knee OA Dx	Unadjusted Incidence Rate[a] (95% CI)	Adjusted Incidence Rate[b] (95% CI)
2005	1,376,053	1681	1.22 (1.16-1.28)	0.51 (0.48-0.55)	1584	1.15 (1.10-1.21)	0.51 (0.48-0.55)	97	0.07 (0.06-0.09)	0.03 (0.02-0.04)
2006	1,365,993	1780	1.30[c] (1.24-1.37)	0.55 (0.51-0.58)	1643	1.20 (1.15-1.26)	0.55 (0.51-0.58)	137	0.10 (0.08-0.12)	0.04 (0.03-0.05)
2007	1,347,056	1777	1.32 (1.26-1.38)	0.55 (0.51-0.59)	1611	1.20 (1.14-1.26)	0.55 (0.51-0.59)	166	0.12 (0.11-0.14)	0.05 (0.04-0.06)
2008	1,374,860	2513	1.83[c] (1.75-1.90)	0.77 (0.72-0.82)	2341	1.70[c] (1.63-1.77)	0.77 (0.72-0.82)	172	0.13 (0.11-0.15)	0.05 (0.04-0.06)
2009	1,402,346	1856	1.32[c] (1.26-1.38)	0.56 (0.52-0.60)	1673	1.19[c] (1.14-1.25)	0.56 (0.52-0.60)	183	0.13 (0.11-0.15)	0.05 (0.04-0.06)
2010	1,417,009	2242	1.58[c] (1.52-1.65)	0.67 (0.63-0.71)	2011	1.42[c] (1.36-1.48)	0.67 (0.63-0.71)	231	0.16 (0.14-0.19)	0.06 (0.05-0.08)
2011	1,415,759	2514	1.78[c] (1.71-1.85)	0.75 (0.70-0.80)	2310	1.63[c] (1.57-1.70)	0.75 (0.70-0.80)	204	0.14 (0.13-0.17)	0.06 (0.04-0.07)
2012	1,389,012	2438	1.76 (1.69-1.83)	0.73 (0.69-0.78)	2236	1.61 (1.54-1.68)	0.73 (0.69-0.78)	202	0.15 (0.13-0.17)	0.06 (0.04-0.07)
2013	1,376,179	2175	1.58[c] (1.52-1.65)	0.66 (0.62-0.70)	1962	1.43[c] (1.36-1.49)	0.66 (0.62-0.70)	213	0.16 (0.14-0.18)	0.06 (0.05-0.07)
2014	1,356,639	2342	1.73[c] (1.66-1.80)	0.74 (0.69-0.79)	2133	1.57[c] (1.51-1.64)	0.74 (0.69-0.79)	209	0.15 (0.13-0.18)	0.06 (0.05-0.07)
Total	13,820,906	21,318	1.54		19,504	1.41		1814	0.13	

OA, osteoarthritis.
[a] Rate per 1000 person-years.
[b] Adjusted for age group, gender, rank, and service.
[c] Statistically significant.

knee increased by 100% from 0.03 (95% CI, 0.02-0.04) in 2005 to 0.06 (95% CI, 0.05-0.07) in 2014.

Increasing age was a significant risk factor for both primary and secondary OA, with IRR increased sequentially with increasing age categories (Tables 2, 3, and 4). Those aged >40 years had the highest IRR, >100 times greater than those aged <20 (IRR, 126.05; 95% CI, 95.79-165.88 and IRR, 119.85; 95% CI, 48.85-294.07 for primary and secondary OA of the knee, respectively).

No significant difference in IR was found between overall male and female servicemembers for primary or secondary OA of the knee, although the IRR for secondary OA in men was slightly greater than in women and approached significance (IRR, 1.13; 95% CI, 0.98-1.30, $P = .085$). Stepwise Poisson regression analysis for the effect of gender in different age groups showed that female gender was independently associated with a decreased IRR among servicemembers in <20, 20-24, and 25-29 age groups (Table 5). Female gender increased the risk of OA in the 35-39 age group. There was no significant difference in risk for OA of the knee attributable to gender for the 30-34 and >40 age groups. The results do not seem to be influenced by differences in the numbers of male and female servicemembers within each category.

Race was also associated with differences in risk for OA where self-identified black and other servicemembers had an increased IRR of primary OA of the knee compared with white servicemembers (IRR, 1.54; 95% CI, 1.49-1.60 and IRR, 1.3, 95% CI, 1.26-1.37, respectively). In addition, self-identified black servicemembers had a greater IRR than white servicemembers for secondary OA of the knee (IRR, 1.40; 95% CI, 1.25-1.56), whereas no significant difference in IRR for secondary OA of the knee was seen between white and other categories.

An increase in IRR for both primary and secondary OA of the knee was seen among senior enlisted and senior officer categories compared with junior enlisted (senior enlisted primary OA: IRR, 1.49; 95% CI, 1.39-1.60 and secondary OA: IRR, 1.67; 95% CI, 1.34-2.08; senior officer primary OA: IRR, 1.59; 95% CI, 1.39-1.60; secondary OA: IRR, 1.67; 95% CI, 1.32-2.13). The IRR of primary OA of

Table 2
Incidence of OA of the Knee by Demographic Category.

Category	Person-Years	Total No. of Knee OA Dx	Unadjusted Incidence Rate[a] (95% CI)	Adjusted Incidence Rate Ratio[b] (95% CI)	*P* Value
Age					
<20	895,628	61	0.07 (0.05-0.09)	1	—
20-24	4,554,013	710	0.16 (0.15-0.17)	2.36 (1.81-3.07)	<.0001
25-29	3,203,388	1514	0.47 (0.45-0.50)	7.13 (5.48-9.27)	<.0001
30-34	2,066,974	2002	0.97 (0.93-1.01)	14.75 (11.33-19.21)	<.0001
35-39	1,623,333	5663	3.49 (3.40-3.58)	53.91 (41.46-70.11)	<.0001
>40	1,477,570	11,368	7.69 (7.55-7.83)	125.64 (96.63-163.35)	<.0001
Gender					
Male	11,813,812	18,292	1.55 (1.53-1.57)	0.99 (0.95-1.03)	.6987
Female	2,007,094	3026	1.51 (1.45-1.56)	1	—
Race					
White	9,570,253	12,181	1.27 (1.25-1.30)	1	—
Black	2,370,904	5899	2.49 (2.43-2.55)	1.53 (1.48-1.58)	<.0001
Other	1,879,749	3238	1.72 (1.66-1.78)	1.27 (1.23-1.33)	<.0001
Rank					
Junior enlisted (E1-E4)	6,024,373	1975	0.33 (0.31-0.34)	1	—
Senior enlisted (E5-E9)	5,473,994	14,025	2.56 (2.52-2.61)	1.50 (1.41-1.61)	<.0001
Junior officer (O1-O4)	1,413,877	1461	1.03 (0.98-1.09)	1.00 (0.95-1.73)	.9437
Senior officer (O5-O9)	908,662	3857	4.24 (4.11-4.37)	1.60 (1.49-1.73)	<.0001
Service					
Army	5,246,374	9492	1.81 (1.77-1.85)	1.24 (1.17-1.32)	<.0001
Navy	3,305,941	3842	1.16 (1.13-1.20)	0.86 (0.81-0.91)	<.0001
Marines	1,965,613	1372	0.70 (0.66-0.74)	1	—
Air Force	3,302,978	6612	2.00 (1.95-2.05)	1.39 (1.31-1.47)	<.0001

OA, osteoarthritis.
[a] Rate per 1000 person-years.
[b] Adjusted for age group, gender, rank, and service.

Table 3
Incidence of Primary OA of the Knee by Demographic Category.

Category	Person-Years	No. of 1° OA Dx	Unadjusted Incidence Rate[a] (95% CI)	Adjusted Incidence Rate Ratio[b] (95% CI)	*P* Value
Age					
<20	895,628	56	0.06 (0.05-0.08)	1	<.0001
20-24	4,554,013	633	0.14 (0.13-0.15)	2.30 (1.74-3.03)	<.0001
25-29	3,203,388	1340	0.42 (0.40-0.44)	6.89 (5.23-9.07)	<.0001
30-34	2,066,974	1786	0.86 (0.83-0.91)	1.44 (1.09-1.89)	<.0001
35-39	1,623,333	5224	3.22 (3.13-3.31)	5.42 (4.12-7.14)	<.0001
>40	1,477,570	10,465	7.08 (6.95-7.22)	126.05 (95.79-165.88)	<.0001
Gender					
Male	11,813,812	16,706	1.41 (1.39-1.44)	0.98 (0.94-1.02)	.3476
Female	2,007,094	2798	1.39 (1.34-1.44)	1	—
Race					
White	9,570,253	11,084	1.16 (1.14-1.18)	1	—
Black	2,370,904	5399	2.28 (2.22-2.34)	1.54 (1.49-1.60)	<.0001
Other	1,879,749	3021	1.61 (1.55-1.66)	1.31 (1.26-1.37)	<.0001
Rank					
Junior enlisted (E1-E4)	6,024,373	1762	0.29 (0.28-0.31)	1	—
Senior enlisted (E5-E9)	5,473,994	12,841	2.35 (2.31-2.39)	1.49 (1.39-1.60)	<.0001
Junior officer (O1-O4)	1,413,877	1334	0.94 (0.89-0.99)	1.00 (0.94-1.06)	.9971
Senior officer (O5-O9)	908,662	3567	3.93 (3.79-4.05)	1.59 (1.39-1.60)	<.0001
Service					
Army	5,246,374	8570	1.63 (1.60-1.67)	1.21 (1.13-1.28)	<.0001
Navy	3,305,941	3548	1.07 (1.04-1.11)	0.85 (0.80-0.91)	<.0001
Marines	1,965,613	1266	0.64 (0.61-0.68)	1	—
Air Force	3,302,978	6120	1.85 (1.81-1.90)	1.38 (1.30-1.47)	<.0001

OA, osteoarthritis.
[a] Rate per 1000 person-years.
[b] Adjusted for age group, gender, rank, and service.

the knee for each of the branches of the armed services from lowest to highest were Navy (IRR, 0.85; 95% CI, 0.80-0.91), Marines (IRR, 1), Army (IRR, 1.21; 95% CI, 1.13-1.28), and Air Force (IRR, 1.38; 95% CI, 1.30-1.47). In addition, a significant difference in IRR was seen for secondary OA of the knee between the Marines (IRR, 1), Air Force (IRR, 1.42; 95% CI, 1.15-1.76), and Army (IRR, 1.66; 95% CI, 1.36-2.04). No difference was seen between IRR for secondary OA of the knee among the Marines (IRR, 1) and Navy (IRR, 0.91, 95% CI; 0.73-1.14).

Discussion

OA is the most common cause of disability in the United States, accounting for 8.6 million disability claims in 2008 [23]. In 2003, the total cost of arthritis and other rheumatic conditions in all joints was $128 billion in the United States alone, with OA the most common form of arthritis [24]. The average direct and indirect costs of OA per person-year in 2003 were $1752 and $1,590, respectively [24].

Table 4
Incidence of Secondary OA of the Knee by Demographic Category.

Category	Person-Years	No. of 2° OA Dx	Unadjusted Incidence Rate[a] (95% CI)	Adjusted Incidence Rate Ratio[b] (95% CI)	*P* Value
Age					
<20	895,628	5	0.01 (0.00-0.01)	1	<.0001
20-24	4,554,013	77	0.02 (0.01-0.02)	3.01 (1.21-7.44)	<.0001
25-29	3,203,388	174	0.05 (0.00-0.06)	9.66 (3.94-23.69)	<.0001
30-34	2,066,974	216	0.11 (0.09-0.12)	18.88 (7.67-46.48)	<.0001
35-39	1,623,333	439	0.27 (0.25-0.30)	50.00 (20.36-122.79)	<.0001
>40	1,477,570	903	0.61 (0.57-0.65)	119.85 (48.85-294.07)	<.0001
Gender					
Male	11,813,812	1586	0.13 (0.12-0.14)	1.13 (0.98-1.30)	.0848
Female	2,007,094	228	0.11 (0.10-0.13)	1	—
Race					
White	9,570,253	1097	0.11 (0.10-0.13)	1	—
Black	2,370,904	500	0.21 (0.19-0.23)	1.40 (1.25-1.56)	<.0001
Other	1,879,749	217	0.12 (0.10-0.13)	0.93 (0.80-1.07)	.3073
Rank					
Junior enlisted (E1-E4)	6,024,373	213	0.04 (0.03-0.04)	1	—
Senior enlisted (E5-E9)	5,473,994	1184	0.22 (0.20-0.23)	1.67 (1.34-2.08)	<.0001
Junior officer (O1-O4)	1,413,877	127	0.09 (0.08-0.11)	1.01 (0.84-1.21)	.9087
Senior officer (O5-O9)	908,662	290	0.32 (0.28-0.36)	1.67 (1.32-2.13)	<.0001
Service					
Army	5,246,374	922	0.18 (0.17-0.19)	1.66 (1.36-2.04)	<.0001
Navy	3,305,941	294	0.09 (0.08-0.10)	0.91 (0.73-1.14)	.4248
Marines	1,965,613	106	0.05 (0.04-0.07)	1	—
Air Force	3,302,978	492	0.15 (0.14-0.16)	1.42 (1.15-1.76)	.0012

OA, osteoarthritis.
[a] Rate per 1000 person-years.
[b] Adjusted for age group, gender, rank, and service.

Table 5
Effect of Gender at Different Age Categories.

Age	Adjusted RR of Female Servicemembers (95% CI)	*P* Value
<20	0.38 (0.22-0.64)	.0003
20-24	0.58 (0.49-0.69)	<.0001
25-29	0.86 (0.75-0.98)	.0194
30-34	0.95 (0.84-1.07)	.4062
35-39	1.23 (1.13-1.33)	<.0001
>40	0.98 (0.93-1.03)	.4265

Given the significant financial burden, several studies have described the incidence and prevalence of this condition in the United States, but none have examined epidemiology on scale comparable to our study. Through our analysis, we determined that the incidence of primary and secondary OA of the knee among US active duty military from 2005 to 2014 was 1.41 per 1000 person-years and 0.13 per 1000 person-years, respectively. The incidence of primary and secondary OA of the knee varied between years, and both showed a trend toward an increasing incidence over the course of our study. In accordance with existing knowledge about the natural history of knee OA, the incidence of primary OA of the knee was greater than that of secondary OA of the knee for every subgroup [25].

Previous studies have identified several risk factors for the development of OA of the knee. One meta-analysis showed a strong association with previous trauma and BMI, as 5.1% cases of incident OA of the knee were associated with previous injury and 24.6% were associated with obesity or being overweight [8]. Another meta-analysis found that a 5-point increase in BMI conferred a 35% increased risk of degenerative joint disease [7]. Accordingly, the fighting loads and high-impact activity inherent to military combat and drills likely increase joint strain. Furthermore, there is also strong evidence that genetic factors play a significant role in the development of OA [26]. Although we were unable to assess the effect of BMI on our population, several risk factors for both incident primary and secondary OA were identified. Furthermore, owing to strict height, weight, and physical fitness standards maintained in active duty military, the risk factors identified are likely contributory even when the rate of obesity is low. We found that increasing age, nonwhite race, senior rank, and service in the Air Force, Army, and Marines increased the risk of primary OA.

PTOA and other secondary etiologies such as prior knee surgery, gout, rheumatoid arthritis, and knee malalignment account for a sizable percentage of all cases of OA of the knee. One study examining the prevalence of PTOA found that approximately 9.8% of OA of the knee occurred secondary to documented joint trauma [25]. The rate of knee OA 10 years after anterior cruciate ligament tear is likely up to 50% [27], and OA may occur in up to 50% 10-20 years after partial meniscectomy [27,28]. In addition, a meta-analysis of 24 observational studies estimated that specified knee injuries to cartilage, ligaments, or femur conferred an odds ratio of 5.95 (95% CI, 4.57-7.75) for the development of OA of the knee [29]. Although the rate of PTOA after knee injury is high, there are no studies examining the incidence of PTOA of the knee relative to primary OA of the knee.

PTOA represents a significant health burden among the military population. In a study by Rivera et al [13], arthritis was the most common reason for failure of the Army Physical Examination Board evaluation, accounting for 70% of service-limiting disabilities. Of the cases unfit for duty due to arthritis, 94.4% occurred secondary to prior traumatic injury. The knee was the third most commonly injured joint after the spine and shoulder and had an average disability rating of 11%. Finally, 100% of traumatic knee injuries resulted in PTOA in their cohort [13]. Although the risk factors for secondary OA of the knee were similar to those of primary OA, risk was only significantly increased for black servicemembers and service in ground-based forces.

Increasing age had the most significant impact on development of both primary and secondary OA, with a statistically significant stepwise increase in IRR for both primary and secondary OA of the knee for each of the age categories. This finding is consistent with several other studies identified in a review by Silverwood et al [8]. Another study of OA in the military population found that the risk of all forms of OA exponentially increased with age [15]. The most substantial increase in relative risk for primary OA occurred over age 40. In contrast, the relative risk for secondary OA increased earlier in age groups 30-34 and 35-39. This reflects the findings of a large study on prevalence of OA among patients of the University of Iowa Hospitals and Clinic System by Brown et al [25] in which patients presenting with PTOA were 10.4 years younger than those with primary OA of the knee. In addition, all patients in one study after the rehabilitation of patients suffering from PTOA after war injuries were <40 years of age [30]. Another study on long-term disability from war injury found degenerative arthritis to be the most common unfitting condition for the return to active duty where the average age of patients in the cohort was 26 [14].

Unlike previous studies, female gender actually decreased the risk of knee OA for all individuals aged <30 years in our population, and only females aged 35-39 years demonstrated a significantly increased IRR [8,9,16]. Prior investigations have preferentially focused on risk factors for OA among an older demographic. Based on the current findings, female gender may be protective against OA of the knee for those aged <30 years, although this may transition to a risk factor among individuals aged ≥55 years [31]. This finding highlights the need to further elucidate the interplay between age and other risk factors of OA of the knee. Interestingly, another study of the incidence of OA among the military population found that the adjusted IR of all forms of OA was 20% higher in women than in men [15]. Although female gender is a well-established risk factor for the development of OA, the risk of developing secondary OA of the knee was slightly higher in men than in women and only approached statistical significance for secondary OA ($P = .085$). This possible difference may be attributable to unique characteristics of our patient cohort, where male armed servicemembers are more likely to engage in higher demand occupational duties and sustain combat-related joint injuries that contribute to PTOA [13].

Nonwhite ethnicity was also found to be a significant risk factor for incident OA of the knee. Two other studies reported similar findings in investigations of hip and cumulative rates of OA [15,16]. Prior studies have posited that these underlying differences may be attributable to the increased bone mineral density [32], muscle mass, and BMI among those of black race [15,16,33]. Finally, the development of OA appears to be influenced by several genetic factors, many of which are specific to race or ethnicity [26,34,35].

In our study, senior-ranking enlisted servicemembers also experienced an increased risk of both primary and secondary OA of the knee compared with their junior-ranking counterparts. While it should be noted that age and rank are associated, military rank is principally correlated with total years of service. Therefore, the increased risk of primary and secondary OA of the knee in senior-ranking servicemembers could be attributed to greater exposure to occupational risk factors inherent to military service. With regard to the branch of military service, the IRs for primary and secondary OA were greatest in the Marines, Army, and Air Force. Although demographic differences between service branches exist, differences in the adjusted IRRs demonstrate that branch of military service is an independent risk factor for OA of the knee. This trend was more evident for cases of secondary OA, which correlate with heightened risk of extremity trauma through combat or

disease/nonbattle injuries. Furthermore, Army and Marine servicemembers must often navigate extreme terrain while carrying heavy loads and are more physically engaged in conflict.

Several studies have linked strenuous physical activity to OA of the knee. One study of elite Finnish athletes showed a 1.8- to 4-fold greater risk for developing knee OA compared with a control population [36]. Another historical study on occupational risk factors found an increased risk of OA of the knee among the British dockworkers compared with a control group of lower-demand, civil servants [37]. A meta-analysis by McWilliams et al [10] identified heavy work, kneeling, elite sports, and knee strain as occupational risk factors for OA of the knee. Numerous studies have demonstrated an increased incidence of OA of the knee among current and past high-level athletes [38-42]. Owing to the nature of military service, it is likely that occupational exposure to these risk factors was high in our population, particularly among ground-based forces [16].

Some of the limitations of previous studies include variability of OA diagnosis, small study size, and limited demographic sampling [5,11,12]. Many of the best available studies of prevalence and risk factors are limited by their isolated reporting of radiographic prevalence [4-6] or overreliance on subjective, patient-reported data without clinical correlation [43,44]. Although radiographic evidence of OA may be a useful support for clinical diagnosis, the high sensitivity and low specificity of osteoarthritic changes in weight-bearing knee radiographs may lead to overrepresentation of the prevalence of knee OA [11]. In addition, the use of subjective patient complaints of knee pain is not a reliable proxy for OA.

This study's limitations include those inherent to database use. Although we had access to a large fund of demographic data, we were unable to analyze our cohort for other potential risk factors because of patient deidentification during entry. For example, DMED does not include biometric data such as BMI or other personal health information such as family history. Furthermore, coding error and diagnostic criteria variability among health care providers may also affect IRs. Finally, due to increased physical standards, frequent load-bearing activities, and greater risk for extremity trauma, servicemembers have greater occupational risk factor exposure than the general population. However, the unique characteristics of our patient population are strengths of this study. Clinical series evaluating knee OA among young adults are very limited, and more data about the natural history of both primary and secondary OA are warranted, both to understand the pathogenesis of this disease and guide preventative measures. Finally, our database is among the largest reported to date and represents a closed health care system, accounting for 13,820,906 person-years.

Conclusion

This study is the first report of incidence and risk factors for OA of the knee in a large athletic population. We determined that chronologic age, race, rank, and branch of service all correlated with the incidence of both primary and secondary knee OA in an active population. In contrast to existing studies, we found that female gender was associated with a decreased risk of OA of the knee in those aged <30 years. This is also the first study to identify senior rank, and by proxy, years of military service, as a risk factor for OA of the knee. Differences in the risk of knee OA between military service branches can inform strategies to mitigate the effects of active duty service. Our findings reflect the current understanding of risk factors for OA of the knee. In view of to the high incidence and significant health care burden of OA of the knee among the military population, more studies regarding occupational risk factors are warranted. In addition, this study highlights the need for better prevention strategies, especially among those with documented knee joint trauma and prolonged military careers.

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