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Anterior Cruciate Ligament Injury Risk in Sport: A Systematic Review and Meta-Analysis of Injury Incidence by Sex and Sport Classification

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Objective: To evaluate sex differences in incidence rates (IRs) of anterior cruciate ligament (ACL) injury by sport type (collision, contact, limited contact, and noncontact).

Data Sources: A systematic review was performed using the electronic databases PubMed (1969–January 20, 2017) and EBSCOhost (CINAHL, SPORTDiscus; 1969–January 20, 2017) and the search terms *anterior cruciate ligament* AND *injury* AND (*incidence* OR *prevalence* OR *epidemiology*).

Study Selection: Studies were included if they provided the number of ACL injuries and the number of athlete-exposures (AEs) by sex or enough information to allow the number of ACL injuries by sex to be calculated. Studies were excluded if they were analyses of previously reported data or were not written in English.

Data Extraction: Data on sport classification, number of ACL injuries by sex, person-time in AEs for each sex, year of publication, sport, sport type, and level of play were extracted for analysis.

Data Synthesis: We conducted IR and IR ratio (IRR) meta-analyses, weighted for study size and calculated. Female and male athletes had similar ACL injury IRs for the following sport types: collision (2.10/10 000 versus 1.12/10 000 AEs, IRR = 1.14, $P = .63$), limited contact (0.71/10 000 versus 0.29/10 000 AEs, IRR = 1.21, $P = .77$), and noncontact (0.36/10 000 versus 0.21/10 000 AEs, IRR = 1.49, $P = .22$) sports. For contact sports, female athletes had a greater risk of injury than male athletes did (1.88/10 000 versus 0.87/10 000 AEs, IRR = 3.00, $P < .001$). Gymnastics and obstacle-course races were outliers with respect to IR, so we created a sport category of fixed-object, high-impact rotational landing (HIRL). For this sport type, female athletes had a greater risk of ACL injury than male athletes did (4.80/10 000 versus 1.75/10 000 AEs, IRR = 5.51, $P < .001$), and the overall IRs of ACL injury were greater than all IRs in all other sport categories.

Conclusions: Fixed-object HIRL sports had the highest IRs of ACL injury for both sexes. Female athletes were at greater risk of ACL injury than male athletes in contact and fixed-object HIRL sports.

Key Words: epidemiology, knee, sprain, athletes

Anterior cruciate ligament (ACL) injury is a common and debilitating injury among athletes. It can occur from both contact and noncontact mechanisms[1,2] and has a relatively high incidence in sports involving deliberate contact.[1] The relationship between the amount of inherent contact in a sport and the risk of injury to the ACL is unclear, especially when including sex as a variable. In the United States, collision sports, such as football, rugby, and wrestling, are male dominated. Females play collision sports such as ice hockey and rugby, but contact sports such as soccer and basketball are more commonly cited when comparing ACL injury risk by sex. Whereas the rate of ACL injury in females playing soccer was among the highest, it was also high in limited-contact and noncontact sports, including alpine skiing and gymnastics, respectively.[1,3] Hootman et al[1] found some of the highest rates of ACL injury among males in collision sports (spring and fall football and wrestling). Conversely, in females, gymnastics (noncontact), followed by soccer and basketball, resulted in the highest rates of ACL injury.[1]

Deliberate contact during sport is believed to contribute to increased rates of ACL injury.[4] However, given that many ACL injuries result from noncontact mechanisms, the role of sport type in ACL injury is uncertain. Moreover, it is unclear if a sex difference in ACL injury incidence exists when stratifying by sport type (eg, collision, full contact, limited contact, and noncontact). Therefore, the purpose of our systematic review and meta-analysis was to compare the incidence rates (IRs) of ACL injury of male and female athletes in each of the following sport types: collision, contact, limited contact, and noncontact.

METHODS

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses[5] (PRISMA) guidelines when conducting and reporting this systematic review and meta-analysis.

Literature Search

A systematic review of the current literature was performed using the electronic databases PubMed (1969–January 20, 2017) and EBSCOhost (CINAHL and SPORTDiscus; 1969–January 20, 2017) and the following search terms: *anterior cruciate ligament* AND *injury* AND (*incidence* OR *prevalence* OR *epidemiology*). Results were further limited to peer-reviewed articles written in English.

In addition to the electronic search, we contacted experts in the field for further suggestions and examined references cited in review papers to identify any other relevant articles for potential inclusion. Publication details from all studies identified in the literature search were exported to bibliographic software (Endnote X7; Clarivate Analytics, Philadelphia, PA).

Selection Criteria

Given the large number of identified studies, a single author (A.M.M.) performed the initial screening of articles for inclusion. Any gray areas were discussed with the second author (D.K.S.), and any disagreements were decided by the senior author (G.D.M.). Articles were screened first by title, second by abstract, and third by full text according to the inclusion and exclusion criteria. We included articles in which the total number of ACL injuries and the total number of athlete-exposures (AEs) were reported by sex and the data were provided in such a way that the number of ACL injuries by sex could be calculated. We excluded articles that included further analyses on previously reported prospective studies, were written in languages other than English, or were review papers. Full texts were retrieved when the title or abstract met the selection criteria or when the status could not be determined from the title and abstract alone.

Data Extraction and Analysis

The primary variables extracted were the sport classification, number of ACL injuries for each sex, and person-time in AEs for each sex. Sports were classified as follows: *collision* (contact with an opponent or object is inherent), *contact* (contact with an opponent or object is acceptable), *limited contact* (contact with an opponent or object is discouraged), and *noncontact* (contact with an opponent or object is unexpected; Table 1). For each sport classification, we calculated the overall ACL injury rate and separate IRs for men and women. The IR ratio (IRR) between men and women was subsequently calculated using only data from studies in which injury-risk data were reported for both men and women to allow direct comparisons. Additional extracted data included year of publication, sport, sport type, and level of play. One author (A.M.M.) recorded all pertinent data from the included articles, and another author (D.K.S.) independently reviewed those data for accuracy and completeness.

Table 1. Sport Classification Key

Classification	Sport
Collision	Boxing
	Boys'/men's lacrosse
	Close-quarters combat
	Football
	Handball
	Ice hockey
	Rugby
	Wrestling
Contact	Basketball
	Field hockey
	Girls'/women's lacrosse
	Judo
	Soccer
Limited contact	Baseball
	Cheerleading
	Fencing
	Flickerball
	Floorball
	Frisbee
	Softball
	Volleyball
Noncontact	Alpine skiing
	Dance/ballet
	Running/track
Fixed-object high-impact rotational landing	Gymnastics
	Indoor obstacle-course test
	Obstacle-course race

The reported person-time unit was not uniform across studies. Therefore, to establish a common metric, we tabulated AEs. When the number of player-hours was reported, the number of AEs was estimated by dividing player-hours by 2. The assumption for converting player-hours to AEs was that each AE (1 game or 1 practice) on average would last about 2 hours. In addition, not all authors reported the number of ACL injuries by sex; instead, they provided IRs by sex. For these studies, the number of AEs and the reported IRs were used to calculate the number of ACL injuries by sex (number of ACL injuries by sex = total AEs by sex × the rate numerator by sex/the rate denominator by sex).[6–8] For studies in which the number of ACL injuries by sex could not be estimated, we e-mailed the authors to gather those data. If they did not have access to the information or did not respond, the study was excluded from the meta-analysis.[9–15]

Risk of Bias Assessment

Included studies were critically appraised independently by 2 authors (A.M.M., D.K.S.). Given that most included articles described observational cohort studies that did not include an intervention, traditional checklists were not appropriate. After a thorough search for tools to appraise observational cohort studies, we decided that the tool best suited to be used quantitatively was the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.[16] This tool, available through the National Institutes of Health (Bethesda, MD), assesses criteria such as participation rate, whether exposure data were collected before the outcome, whether the time frame was sufficient to allow for the outcome to occur, and the number of participants lost to follow-up after baseline. If a criterion was met, the item was scored as 1. If it was absent or not reported, the item

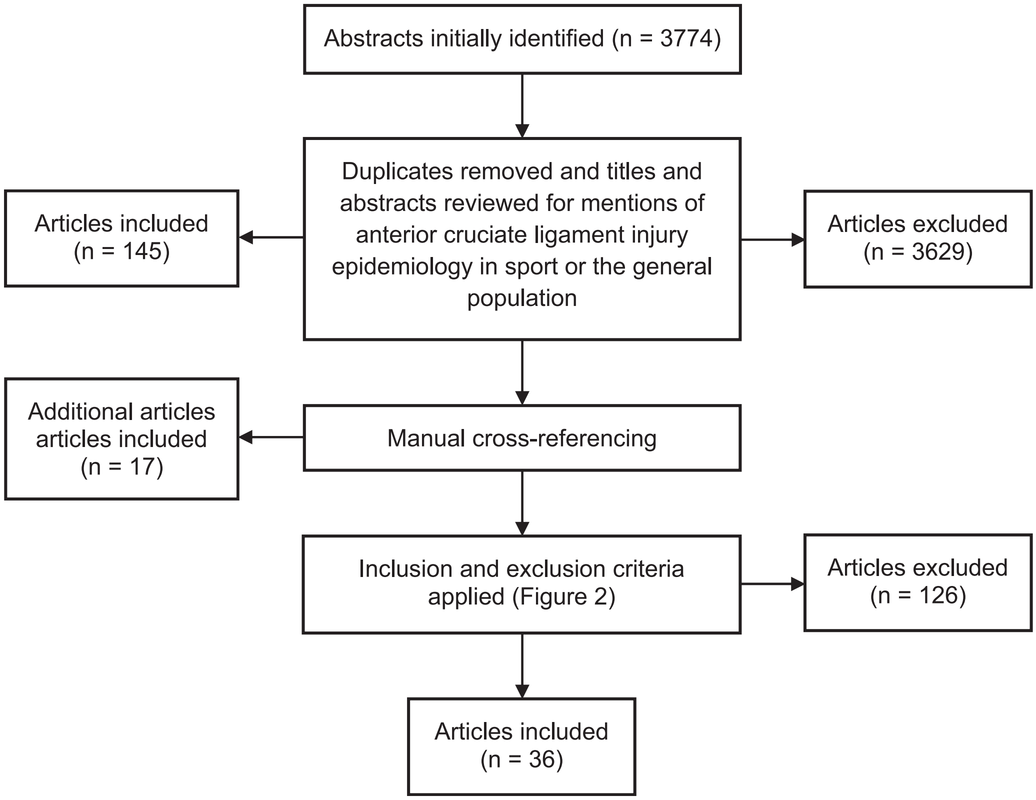


Figure 1. Flow chart of the literature review process.

was scored as zero. The maximum score possible was 14. Items were scored independently by 2 authors (A.M.M., D.K.S.). These authors discussed any discrepancies in scoring. For discrepancies that could not be resolved, a third author (G.D.M.) was consulted for arbitration. Given that the included studies with interventions were treated as cohort studies in the analyses, they were assessed with the same tool, which allowed for quality comparisons across all included studies.

Statistical Analysis

The number of included studies per analysis varied. For the total IR, any study in which authors reported the rate of either sex was included. For the IR by sex, any study in which the authors reported female or male rates was included for the respective analyses. Only studies that included both female and male athletes were used to calculate ratios. The ACL injury IR in noncontact sports comprised sports with marked differences in ACL injury IRs. Given that several outliers were present, we subdivided the category into sports that did and sports that did not include a fixed-object and high-impact landing. These latter sports were removed from the noncontact category, and a new fixed-object, high-impact rotational-landing (HIRL) category was created. *Fixed-object HIRL sports* were defined as noncontact sports that included high-impact landings from fixed objects, such as beams, vaults, and obstacles. Injury IRs for the individual studies were summarized in forest plots for the following groups by total, female, and male IRs: collision, contact, limited-contact, noncontact, and fixed-object HIRL sports. These rates were multiplied to calculate ACL injury IRs per 10 000 AEs in each respective group. Incidence rate ratios for women versus men were calculated for each group and summarized in forest plots.

Injury data were analyzed using R (version 3.3.2; R Foundation for Statistical Computing, Vienna, Austria) and the R packages meta and metafor with the functions metarate for IR and metainc for IRR weighted for individual study size. When AEs but no events (ACL injuries) were present, a continuity correction was applied. The default value for the continuity correction, 0.5, was used to calculate individual point estimates and the 95% confidence interval (CI) and to conduct a meta-analysis based on the inverse variance method. We set the α level at .05.

RESULTS

The electronic literature search yielded 3774 abstracts for initial review. After duplicates were removed, a total of 1300 unique titles remained. We screened the titles and abstracts and removed 1155 articles for lack of relevance to the research. The remaining 145 articles were manually cross-referenced, and experts were consulted to identify additional relevant articles, resulting in the inclusion of 17 more articles. Full texts of these 162 articles were obtained and assessed for the inclusion and exclusion criteria. We contacted the corresponding authors of the included articles for additional information as needed. At the end of the search, 36 articles were included in the study.[1,6–8,17–48] An outline of the literature review process is presented in Figure 1. The data that were extracted for each analysis and can be used to determine which studies were included in each analysis are shown in Table 2.

Authors	Total No. of Anterior Cruciate Ligament Injuries[a]	Total Exposure Per 10 000 Athlete-Exposures	Rate	95% CI	Weight, %
Agel et al[38] (2016)	513	301.76	1.70	1.56, 1.85	3.8
Agel et al[38] (2016)	18	65.00	0.28	0.17, 0.44	3.1
Agel et al[38] (2016)	46	35.38	1.30	0.97, 1.74	3.5
Agel et al[38] (2016)	34	22.67	1.50	1.07, 2.10	3.4
Beynnon et al[17] (2014)	7	12.16	0.58	0.27, 1.21	2.3
Beynnon et al[17] (2014)	6	7.17	0.84	0.38, 1.86	2.2
Beynnon et al[17] (2014)	8	14.42	0.55	0.28, 1.11	2.4
Beynnon et al[17] (2014)	3	1.84	1.63	0.53, 5.05	1.5
Beynnon et al[17] (2014)	9	3.26	2.76	1.44, 5.30	2.5
Brooks et al[6] (2005)	2	9.82	0.20	0.05, 0.81	1.2
Dallalana et al[18] (2007)	9	10.89	0.83	0.43, 1.59	2.5
Dragoo et al[19] (2012)	318	222.22	1.43	1.28, 1.60	3.8
Gwinn et al[22] (2000)	7	3.13	2.24	1.07, 4.70	2.3
Gwinn et al[22] (2000)	3	1.19	2.52	0.81, 7.82	1.5
Hootman et al[1] (2007)	2538	1314.29	1.93	1.86, 2.01	3.8
Hootman et al[1] (2007)	81	140.00	0.58	0.47, 0.72	3.6
Hootman et al[1] (2007)	131	109.17	1.20	1.01, 1.42	3.7
Hootman et al[1] (2007)	147	133.64	1.10	0.94, 1.29	3.7
Joseph et al[23] (2013)	286	258.06	1.11	0.99, 1.24	3.8
Joseph et al[23] (2013)	27	80.94	0.33	0.23, 0.49	3.3
Levy et al[26] (1997)	21	5.83	3.60	2.35, 5.52	3.1
Mountcastle et al[29] (2007)	2	3.96	0.51	0.13, 2.02	1.2
Mountcastle et al[29] (2007)	8	3.92	2.04	1.02, 4.08	2.4
Mountcastle et al[29] (2007)	52	22.33	2.33	1.77, 3.06	3.5
Mountcastle et al[29] (2007)	53	13.18	4.02	3.07, 5.26	3.5
Mountcastle et al[29] (2007)	6	4.70	1.28	0.57, 2.84	2.2
Mountcastle et al[29] (2007)	10	14.90	0.67	0.36, 1.25	2.6
Mountcastle et al[29] (2007)	4	4.82	0.83	0.31, 2.21	1.8
Mountcastle et al[29] (2007)	2	18.78	0.11	0.03, 0.43	1.2
Mountcastle et al[29] (2007)	1	16.54	0.06	0.01, 0.43	0.7
Mountcastle et al[29] (2007)	2	4.13	0.48	0.12, 1.94	1.2
Mountcastle et al[29] (2007)	8	5.02	1.59	0.80, 3.19	2.4
Mountcastle et al[29] (2007)	2	5.29	0.38	0.09, 1.51	1.2
Mountcastle et al[29] (2007)	13	9.60	1.35	0.79, 2.33	2.8
Mountcastle et al[29] (2007)	31	6.28	4.94	3.47, 7.02	3.3
Myklebust et al[44] (2003)	69	10.45	6.60	5.22, 8.36	3.6
Petersen et al[31] (2005)	6	1.19	5.04	2.26, 11.22	2.2
Stanley et al[39] (2016)	22	16.67	1.32	0.87, 2.00	3.2
Random-effects model			1.29	1.07, 1.54	100.0

Heterogeneity: $I^2 = 95\%$, $\tau^2 = 0.2204$, $P < .01$

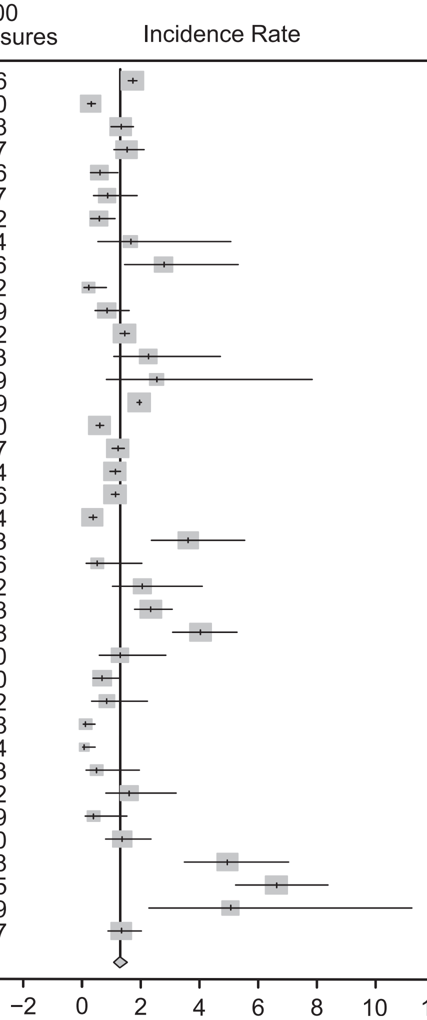


Figure 2. Forest plot for the total incidence rate of anterior cruciate ligament injury in male and female collision-sport athletes combined. [a] Sports are provided in Table 2. Abbreviation: CI, confidence interval.

Incidence Rates for Collision Sports by Sex

In collision sports, the total IR of ACL injury among female and male athletes combined was 1.29/10 000 AEs (95% CI = 1.07, 1.54; $P < .01$, $I^2 = 95.0\%$; Figure 2). The injury IR among female athletes was 2.10/10 000 AEs (95% CI = 1.12, 3.96; $P < .01$, $I^2 = 84.0\%$; Figure 3) and among male athletes was 1.12/10 000 AEs (95% CI = 0.94, 1.33; $P < .01$, $I^2 = 93.0\%$; see Supplemental Figure 1, available online at http://dx.doi.org/10.4085/1062-6050-407-16.S1). We observed no difference between sexes for the ACL injury IR (IRR = 1.14; 95% CI = 0.68, 1.92, $P = .63$; $I^2 = 0\%$; see Supplemental Figure 2).

Incidence Rates for Contact Sports by Sex

The total IR of ACL injury in contact sports was 1.51/10 000 AEs (95% CI = 1.31, 1.75; $P < .01$, $I^2 = 90.0\%$; see Supplemental Figure 3). The injury IR was greater among female (1.88/10 000 AEs; 95% CI = 1.61, 2.20; $P < .01$, $I^2 = 88.0\%$; see Supplemental Figure 4) than among male (0.87/10 000 AEs; 95% CI = 0.69, 1.11; $P < .01$, $I^2 = 84.0\%$; see Supplemental Figure 5) athletes. We observed a difference between sexes for the ACL injury IR (IRR = 3.00; 95% CI = 2.70, 3.34; $P < .001$, $I^2 = 4.0\%$; see Supplemental Figure 6).

Incidence Rates for Limited-Contact Sports by Sex

In limited-contact sports, the total IR of ACL injury was 0.48/10 000 AEs (95% CI = 0.33, 0.70; $P < .01$, $I^2 = 91.0\%$; see Supplemental Figure 7). The injury IR in female athletes was 0.71/10 000 AEs (95% CI = 0.50, 1.01; $P < .01$, $I^2 = 84.0\%$; see Supplemental Figure 8) and in male athletes was 0.29/10 000 AEs (95% CI = 0.18, 0.48; $P < .01$, $I^2 = 63.0\%$; see Supplemental Figure 9). The IRR was calculated using only data from Mountcastle et al,[29] as data comparing injury rates among women and men in this sport type were not available. We observed no difference between sexes for the ACL injury IR (IRR = 1.21; 95% CI = 0.35, 4.20; $P = .77$, $I^2 = 0\%$; see Supplemental Figure 10).

Incidence Rates for Noncontact Sports by Sex

The total IR of ACL injury in noncontact sports was 0.25/10 000 AEs (95% CI = 0.10, 0.65; $P < .01$, $I^2 = 85.0\%$; see Supplemental Figure 11). The ACL injury IR among female athletes was 0.36/10 000 AEs (95% CI = 0.14, 0.96;

Table 2. Data Extracted From Each Included Study Continued on Next Page

Article (y)	Sport	Classification	Level	Anterior Cruciate Ligament Injuries			Athlete-Exposures	
				Female	Male	Total	Female	Male
Agel et al[38] (2016)	Football	Collision	Collegiate	0	513	513	0	3 017 647
Agel et al[38] (2016)	Ice hockey	Collision	Collegiate	3	15	18	150 000	500 000
Agel et al[38] (2016)	Lacrosse	Collision	Collegiate	0	46	46	0	353 846
Agel et al[38] (2016)	Wrestling	Collision	Collegiate	0	34	34	0	226 667
Beynnon et al[17] (2014)	Lacrosse	Collision	High school	0	7	7	0	121 583
Beynnon et al[17] (2014)	Lacrosse	Collision	Collegiate	0	6	6	0	71 731
Beynnon et al[17] (2014)	Football	Collision	High school	0	8	8	0	144 233
Beynnon et al[17] (2014)	Football	Collision	Collegiate	0	3	3	0	18 417
Beynnon et al[17] (2014)	Rugby	Collision	Collegiate	6	3	9	14 723	17 886
Brooks et al[6] (2005)	Rugby	Collision	Professional	0	2	2	0	98 205
Dallalana et al[18] (2007)	Rugby	Collision	Professional	0	9	9	0	108 920
Dragoo et al[19] (2012)	Football	Collision	Collegiate	0	318	318	0	2 222 155
Gwinn et al[22] (2000)	Rugby	Collision	Collegiate	3	4	7	8475	22 788
Gwinn et al[22] (2000)	Instructional wrestling	Collision	Amateur	1	2	3	1306	10 582
Hootman et al[1] (2007)	Football	Collision	Collegiate	0	2538	2538	0	13 142 929
Hootman et al[1] (2007)	Ice hockey	Collision	Collegiate	3	78	81	100 000	1 300 000
Hootman et al[1] (2007)	Lacrosse	Collision	Collegiate	0	131	131	0	1 091 667
Hootman et al[1] (2007)	Wrestling	Collision	Collegiate	0	147	147	0	1 336 364
Joseph et al[23] (2013)	Football	Collision	High school	0	286	286	0	2 580 637
Joseph et al[23] (2013)	Wrestling	Collision	High school	0	27	27	0	809 430
Levy et al[26] (1997)	Rugby	Collision	Collegiate	21	0	21	58 296	0
Mountcastle et al[29] (2007)	Ice hockey	Collision	Collegiate	0	2	2	0	39 587
Mountcastle et al[29] (2007)	Lacrosse	Collision	Collegiate	0	8	8	0	39 204
Mountcastle et al[29] (2007)	Football	Collision	Collegiate	0	52	52	0	223 307
Mountcastle et al[29] (2007)	Football	Collision	Amateur	1	52	53	1828	129 956
Mountcastle et al[29] (2007)	Wrestling	Collision	Collegiate	0	6	6	0	47 039
Mountcastle et al[29] (2007)	Wrestling	Collision	Amateur	0	10	10	0	149 022
Mountcastle et al[29] (2007)	Wrestling	Collision	Amateur	0	4	4	0	48 203
Mountcastle et al[29] (2007)	Close-quarters combat	Collision	Amateur	0	2	2	37 184	150 606
Mountcastle et al[29] (2007)	Boxing	Collision	Amateur	0	1	1	0	165 376
Mountcastle et al[29] (2007)	Boxing	Collision	Amateur	0	2	2	0	41 270
Mountcastle et al[29] (2007)	Handball	Collision	Amateur	4	4	8	25 090	25 090
Mountcastle et al[29] (2007)	Handball	Collision	Amateur	0	2	2	13 564	39 348
Mountcastle et al[29] (2007)	Rugby	Collision	Amateur	0	13	13	770	95 200
Mountcastle et al[29] (2007)	Rugby	Collision	Amateur	0	31	31	0	62 785
Myklebust et al[44] (2003)	Handball	Collision	Elite, subelite	69	0	69	104 468	0
Petersen et al[31] (2005)	Handball	Collision	Semiprofessional, amateur	6	0	6	11 905	0
Stanley et al[39] (2016)	Lacrosse	Collision	High school	0	22	22	0	166 667
Agel et al[38] (2016)	Basketball	Contact	Collegiate	162	70	232	736 364	875 000
Agel et al[38] (2016)	Field hockey	Contact	Collegiate	20	0	20	181 818	0
Agel et al[38] (2016)	Lacrosse	Contact	Collegiate	59	0	59	256 522	0
Agel et al[38] (2016)	Soccer	Contact	Collegiate	71	26	97	710 000	650 000
Beynnon et al[17] (2014)	Basketball	Contact	High school	6	4	10	98 296	108 622
Beynnon et al[17] (2014)	Basketball	Contact	Collegiate	5	2	7	34 882	38 927
Beynnon et al[17] (2014)	Soccer	Contact	High school	15	3	18	114 077	117 140
Beynnon et al[17] (2014)	Soccer	Contact	Collegiate	11	6	17	28 115	30 241
Beynnon et al[17] (2014)	Field hockey	Contact	Collegiate	1	0	1	25 993	0
Beynnon et al[17] (2014)	Field hockey	Contact	High school	4	0	4	82 946	0
Beynnon et al[17] (2014)	Lacrosse	Contact	High school	6	0	6	86 160	0
Beynnon et al[17] (2014)	Lacrosse	Contact	Collegiate	4	0	4	37 567	0
Faude et al[40] (2005)	Soccer	Contact	Elite	11	0	11	17 655	0
Gilchrist et al[20] (2008)	Soccer	Contact	Collegiate	25	0	25	88 139	0
Giza et al[48] (2005)	Soccer	Contact	Professional	8	0	8	177 778	0
Gomez et al[21] (1996)	Basketball	Contact	High school	11	0	11	60 376	0
Gwinn et al[22] (2000)	Basketball	Contact	Collegiate	5	1	6	10 452	11 282
Gwinn et al[22] (2000)	Soccer	Contact	Collegiate	5	1	6	6508	12 408
Gwinn et al[22] (2000)	Basketball	Contact	Amateur	0	5	5	1360	33 866
Gwinn et al[22] (2000)	Soccer	Contact	Amateur	2	10	12	742	25 462

Table 2. Continued From Previous Page and Continued on Next Page

Article (y)	Sport	Classification	Level	Anterior Cruciate Ligament Injuries			Athlete-Exposures	
				Female	Male	Total	Female	Male
Hägglund et al[41] (2009)	Soccer	Contact	Elite	8	8	16	27 078	35 681
Hootman et al[1] (2007)	Basketball	Contact	Collegiate	498	167	665	2 165 217	2 385 714
Hootman et al[1] (2007)	Field hockey	Contact	Collegiate	53	0	53	757 143	0
Hootman et al[1] (2007)	Lacrosse	Contact	Collegiate	145	0	145	852 941	0
Hootman et al[1] (2007)	Soccer	Contact	Collegiate	411	168	579	1 467 857	1 866 667
Joseph et al[23] (2013)	Soccer	Contact	High school	96	44	140	643 206	914 551
Joseph et al[23] (2013)	Basketball	Contact	High school	92	25	117	894 391	1 106 060
Kiani et al[24] (2010)	Soccer	Contact	Amateur	5	0	5	66 505	0
Krutsch et al[42] (2016)	Soccer	Contact	Professional and amateur	0	16	16	0	75 312
LaBella et al[25] (2011)	Soccer, basketball	Contact	High school	12	0	12	22 925	0
Le Gall et al[43] (2008)	Soccer	Contact	Elite, youth	12	0	12	48 359	0
Mandelbaum et al[7] (2005)	Soccer	Contact	Amateur	73	0	73	205 308	0
Messina et al[28] (1999)	Basketball	Contact	High school	0	4	4	0	84 943
Mountcastle et al[29] (2007)	Basketball	Contact	Collegiate	6	0	6	15 300	14 273
Mountcastle et al[29] (2007)	Basketball	Contact	Amateur	1	2	3	3438	19 483
Mountcastle et al[29] (2007)	Basketball	Contact	Amateur	2	12	14	16 896	100 409
Mountcastle et al[29] (2007)	Soccer	Contact	Collegiate	4	5	9	23 080	34 192
Mountcastle et al[29] (2007)	Soccer	Contact	Amateur	0	1	1	1810	10 261
Mountcastle et al[29] (2007)	Soccer	Contact	Amateur	1	13	14	14 382	80 124
Mountcastle et al[29] (2007)	Judo	Contact	Amateur	1	5	6	4600	29 900
Nagano et al[8] (2011)	Basketball	Contact	Elite	23	0	23	254 831	0
Östenberg and Roos[45] (2000)	Soccer	Contact	Elite	3	0	3	4839	0
Pfeiffer et al[32] (2006)	Basketball	Contact	High school	5	0	5	24 378	0
Pfeiffer et al[32] (2006)	Soccer	Contact	High school	1	0	1	15 270	0
Söderman et al[46] (2000)	Soccer	Contact	Elite	5	0	5	7017	0
Stanley et al[39] (2016)	Basketball	Contact	High school	35	12	47	289 256	363 636
Stanley et al[39] (2016)	Lacrosse	Contact	High school	32	0	32	101 266	0
Stanley et al[39] (2016)	Soccer	Contact	High school	31	19	50	173 184	208 791
Steffen et al[33] (2008)	Soccer	Contact	Amateur	9	0	9	66 574	0
Tegnander et al[34] (2008)	Soccer	Contact	Elite	2	0	2	14 810	0
Trojian and Collins[35] (2006)	Basketball	Contact	Professional	9	0	9	45 036	0
Waldén et al[37] (2012)	Soccer	Contact	Amateur	21	0	21	139 149	0
Waldén et al[47] (2011)	Soccer	Contact	Professional	15	20	35	52 389	164 923
Agel et al[38] (2016)	Baseball	Limited contact	Collegiate	0	12	12	0	600 000
Agel et al[38] (2016)	Softball	Limited contact	Collegiate	33	0	33	550 000	0
Agel et al[38] (2016)	Volleyball	Limited contact	Collegiate	30	0	30	500 000	0
Beynnon et al[17] (2014)	Volleyball	Limited contact	Collegiate	1	0	1	2237	0
Hootman et al[1] (2007)	Baseball	Limited contact	Collegiate	0	56	56	0	2 800 000
Hootman et al[1] (2007)	Softball	Limited contact	Collegiate	129	0	129	1 612 500	0
Hootman et al[1] (2007)	Volleyball	Limited contact	Collegiate	142	0	142	1 577 778	0
Joseph et al[23] (2013)	Volleyball	Limited contact	High school	20	0	20	841 608	0
Joseph et al[23] (2013)	Baseball	Limited contact	High school	0	6	6	0	861 964
Joseph et al[23] (2013)	Softball	Limited contact	High school	21	0	21	657 246	0
Mountcastle et al[29] (2007)	Baseball	Limited contact	Collegiate	0	1	1	0	27 674
Mountcastle et al[29] (2007)	Volleyball	Limited contact	Collegiate	2	0	2	19 357	0
Mountcastle et al[29] (2007)	Volleyball	Limited contact	Amateur	0	2	2	6856	38 849
Mountcastle et al[29] (2007)	Fencing	Limited contact	Amateur	0	1	1	12 148	16 964
Mountcastle et al[29] (2007)	Cheerleading	Limited contact	Amateur	2	2	4	16 780	16 780
Mountcastle et al[29] (2007)	Flickerball	Limited contact	Amateur	0	2	2	5845	31 896
Mountcastle et al[29] (2007)	Frisbee	Limited contact	Amateur	0	1	1	925	4829
Pasanen et al[30] (2008)	Floorball	Limited contact	Elite	10	0	10	28 679	0
Stanley et al[39] (2016)	Softball	Limited contact	High school	1	0	1	142 857	0
Stanley et al[39] (2016)	Baseball	Limited contact	High school	0	5	5	0	208 333
Liederbach et al[27] (2008)	Dance	Noncontact	Elite	10	2	12	873 067	545 266
Mountcastle et al[29] (2007)	Track	Noncontact	Collegiate	2	0	2	76 542	114 409
Mountcastle et al[29] (2007)	Skiing	Noncontact	Amateur	1	1	2	3586	20 361
Mountcastle et al[29] (2007)	Parachute	Noncontact	Amateur	0	2	2	8402	42 300
Viola et al[36] (1999)	Alpine skiing	Noncontact	Professional	10	21	31	227 766	499 070

Table 2. Continued From Previous Page

Article (y)	Sport	Classification	Level	Anterior Cruciate Ligament Injuries			Athlete-Exposures	
				Female	Male	Total	Female	Male
Agel et al[38] (2016)	Gymnastics	High-impact rotational landing	Collegiate	24	0	24	100 000	0
Gwinn et al[22] (2000)	Obstacle-course race	High-impact rotational landing	Amateur	4	3	7	650	5289
Hootman et al[1] (2007)	Gymnastics	High-impact rotational landing	Collegiate	134	0	134	406 061	0
Mountcastle et al[29] (2007)	Gymnastics	High-impact rotational landing	Collegiate	1	0	1	14 317	0
Mountcastle et al[29] (2007)	Gymnastics	High-impact rotational landing	Amateur	7	7	14	29 304	166 054
Mountcastle et al[29] (2007)	Obstacle-course race	High-impact rotational landing	Amateur	5	9	14	5323	35 630

$P < .01$, $I^2 = 74.0\%$; see Supplemental Figure 12) and among male athletes was 0.21/10 000 AEs (95% CI = 0.07, 0.62; $P < .01$, $I^2 = 70.0\%$; see Supplemental Figure 13). We observed no difference between sexes (IRR = 1.49; 95% CI = 0.79, 2.79; $P = .22$, $I^2 = 0\%$; see Supplemental Figure 14).

Incidence Rates for Fixed-Object HIRL Sports by Sex

In fixed-object HIRL sports, the total IR of ACL injury was 2.62/10 000 AEs (95% CI = 1.44, 4.75; $P < .01$, $I^2 = 89.0\%$; see Supplemental Figure 15). The ACL injury IR among female athletes was 4.80/10 000 AEs (95% CI = 2.37, 9.70; $P < .01$, $I^2 = 89.0\%$; see Supplemental Figure 16) and among male athletes was 1.75/10 000 AEs (95% CI = 0.41, 7.48; $P < .01$, $I^2 = 89.0\%$; see Supplemental Figure 17). We observed a difference between sexes (IRR = 5.51; 95% CI = 2.80, 10.82; $P < .001$, $I^2 = 0\%$; see Supplemental Figure 18).

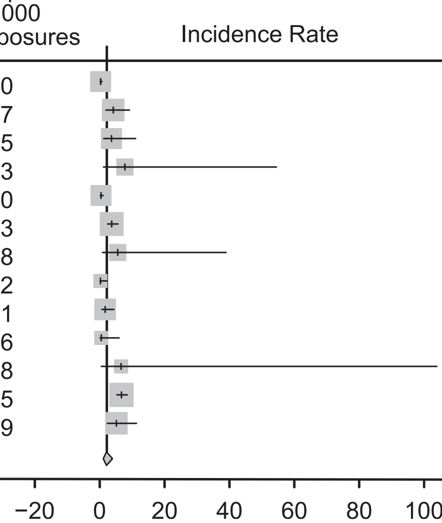
Risk of Bias Assessment

Most studies were of moderate quality (Table 3). Three studies fulfilled 75% or more of the criteria, and 33 studies fulfilled 50% or more of the criteria. The remaining 3 studies fulfilled fewer than 50% of the criteria and were deemed to be of low quality. Studies may have received lower scores for lack of reporting information, such as the total number of eligible individuals, how outcomes were measured, and attrition. Overall, the risk of bias was deemed to be moderate.

DISCUSSION

The purpose of our study was to quantify sex differences in ACL injury risk for sports with various amounts of contact. Female athletes participating in contact and fixed-object HIRL sports had greater ACL injury IRs than their male counterparts. In contrast, the ACL injury IRs for collision, limited-contact, and noncontact sports did not differ between sexes. The findings from this meta-analysis support a previous report[4] indicating that the amount of athlete-to-athlete contact inherent to a sport was correlated with the rate of ACL injury in both male and female athletes. However, adding the fixed-object HIRL category suggested that sports such as gymnastics and obstacle-course races may result in the highest rates of ACL injury.

Authors	No. of Female Anterior Cruciate Ligament Injuries[a]	Female Exposure Per 10 000 Athlete-Exposures	Rate	95% CI	Weight, %
Agel et al[38] (2016)	3.0	15.00	0.20	0.06, 0.62	8.6
Beynnon et al[17] (2014)	6.0	1.47	4.08	1.83, 9.07	10.0
Gwinn et al[22] (2000)	3.0	0.85	3.54	1.14, 10.98	8.6
Gwinn et al[22] (2000)	1.0	0.13	7.66	1.08, 54.36	5.6
Hootman et al[1] (2007)	3.0	10.00	0.30	0.10, 0.93	8.6
Levy et al[26] (1997)	21.0	5.83	3.60	2.35, 5.52	11.3
Mountcastle et al[29] (2007)	1.0	0.18	5.47	0.77, 38.84	5.6
Mountcastle et al[29] (2007)	0.5[b]	3.72	0.13	0.01, 2.15	3.6
Mountcastle et al[29] (2007)	4.0	2.51	1.59	0.60, 4.25	9.2
Mountcastle et al[29] (2007)	0.5[b]	1.36	0.37	0.02, 5.89	3.6
Mountcastle et al[29] (2007)	0.5[b]	0.08	6.49	0.41, 103.81	3.6
Myklebust et al[44] (2003)	69.0	10.45	6.60	5.22, 8.36	11.7
Petersen et al[31] (2005)	6.0	1.19	5.04	2.26, 11.22	10.0
Random-effects model			2.10	1.12, 3.96	100.0



Heterogeneity: $I^2 = 84\%$, $\tau^2 = 0.8766$, $P < .01$

Figure 3. Forest plot for the incidence rate of anterior cruciate ligament injury in female collision-sport athletes. [a] Sports are provided in Table 2. [b] We substituted 0.1 for 0 to estimate an extremely low rate that could be used in the analysis. Abbreviation: CI, confidence interval.

Table 3. Results of Risk of Bias Assessment Using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies[a]

Study (y)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total Present
Agel et al[38] (2016)	1	1	0	1	0	1	1	1	1	1	1	0	0	0	9
Beynnon et al[17] (2014)	1	1	0	1	0	1	1	1	1	0	1	0	0	1	9
Brooks et al[6] (2005)	1	1	1	1	0	1	1	1	1	1	0	0	0	0	9
Dallalana et al[18] (2007)	1	1	1	1	0	1	1	1	1	1	0	0	0	0	9
Dragoo et al[19] (2012)	1	1	0	1	0	1	1	1	1	0	0	0	0	0	7
Faude et al[40] (2005)	1	1	0	1	0	1	1	1	1	1	0	0	0	0	8
Gilchrist et al[20] (2008)	1	1	0	1	0	1	1	1	1	1	1	1	0	0	10
Giza et al[48] (2005)	1	1	1	1	0	1	1	1	1	0	0	0	0	0	8
Gomez et al[21] (1996)	1	1	0	1	0	1	1	1	1	0	0	0	0	0	7
Gwinn et al[22] (2000)	1	1	1	1	0	1	1	1	1	0	1	0	0	0	9
Hägglund et al[41] (2009)	1	1	1	1	0	1	1	0	1	1	0	0	1	0	9
Hootman et al[1] (2007)	1	1	0	1	0	1	1	1	1	1	0	0	0	0	8
Joseph et al[23] (2013)	1	1	1	1	0	0	1	0	0	0	1	0	1	1	8
Kiani et al[24] (2010)	1	1	1	1	0	1	1	1	1	1	1	0	1	1	12
Krutsch et al[42] (2016)	1	1	1	1	0	1	1	0	0	1	1	0	0	0	8
LaBella et al[25] (2011)	1	1	0	1	0	1	1	1	1	1	1	0	1	0	10
Le Gall et al[43] (2008)	1	1	1	1	0	0	1	0	0	0	0	0	1	0	6
Levy et al[26] (1997)	1	1	1	1	0	1	1	1	0	0	1	0	1	0	9
Liederbach et al[27] (2008)	1	1	0	0	0	1	1	1	1	1	1	0	0	0	8
Mandelbaum et al[7] (2005)	1	1	1	1	0	1	1	1	1	1	1	0	0	0	10
Messina et al[28] (1999)	1	0	0	1	0	1	1	1	0	0	0	0	0	0	5
Mountcastle et al[29] (2007)	1	1	1	1	0	1	1	1	1	0	1	0	0	0	9
Myklebust et al[44] (2003)	1	1	1	1	0	1	1	1	1	0	1	0	0	0	9
Nagano et al[8] (2011)	1	0	0	1	0	0	0	1	0	0	0	0	0	0	3
Östenberg and Roos[45] (2000)	1	1	1	1	0	1	1	0	0	1	0	0	1	0	8
Pasanen et al[30] (2008)	1	0	0	1	1	1	1	1	1	1	0	1	1	0	10
Petersen et al[31] (2005)	1	1	0	1	0	1	1	1	1	1	1	0	0	0	9
Pfeiffer et al[32] (2006)	1	1	0	1	0	1	1	1	1	1	1	0	0	0	9
Söderman et al[46] (2000)	1	1	1	1	0	1	1	1	1	0	0	0	0	0	8
Stanley et al[39] (2016)	1	1	0	1	0	1	1	1	1	1	0	0	0	0	8
Steffen et al[33] (2008)	1	1	1	1	1	1	1	1	1	1	1	1	0	1	13
Tegnander et al[34] (2008)	1	1	1	1	0	1	1	1	1	0	0	0	0	0	8
Trojian and Collins[35] (2006)	1	1	1	1	0	1	1	1	1	0	1	0	0	0	9
Viola et al[36] (1999)	1	1	1	1	0	1	1	1	1	0	0	0	0	0	8
Waldén et al[37] (2012)	1	1	1	1	0	1	1	1	1	1	1	1	0	1	12
Waldén et al[47] (2011)	1	1	0	1	0	1	1	1	1	0	0	0	0	0	7

[a] 0 = *criterion was absent or not reported*; 1 = *criterion was present*.

Identifying the ACL injury IR associated with fixed-object HIRL sports is especially relevant as it pertains to military training and activities. Over a 7-year period, the IR of ACL injury in US military members of all services was 3.09/1000 person-years for men and 2.29/1000 person-years for women.[49] Investigators[49] noted that service members were at 10 times greater risk of ACL injury than the general population. This increased risk may be partially explained by participation in fixed-object HIRL activities. In contrast to our findings, Owens et al[49] did not find women to be at greater risk of ACL injury than men; however, they reported person-years because they did not have exposure information. In addition, men outnumbered women in their study[49] and, thus, had higher rates of ACL injury. Military service members, especially those participating in regular training that includes fixed-object HIRLs, may benefit from integrative neuromuscular training to mitigate their risk of ACL injury.

In addition to the military application, our findings related to fixed-object HIRL sports are also relevant considering the advent of recreational obstacle-course races (eg, Tough Mudder, Spartan, BattleFrog). These races are based on military training obstacle courses. Currently, no information about the rates of ACL injury associated with these races is available, but our results suggest that participants should exercise caution. For gymnastics, our findings indicated that the unique demands of the sport, including both implement-based activity and high-impact landings after full-body rotation, distinguish the sport from other noncontact sports regarding the ACL injury risk. Hootman et al[1] found that football, a collision sport, resulted in the greatest incidence of ACL injuries in collegiate male athletes. Our findings indicated that fixed-object HIRL sports resulted in ACL injury IRs that were similar to those of collision sports in men (1.75/10 000 versus 1.12/10 000 AEs). The ACL injury IR was more than 3 times greater among women than among men for fixed-object HIRL sports. Considering the likely mechanisms of injury (landing with rotation, stiff-legged landing), this disparity highlights the neuromuscular deficits typically demonstrated by female athletes.[50] Therefore, female athletes participating in fixed-object HIRL sports may benefit the most from preventive strategies.

We also found that female athletes participating in contact sports sustained ACL injuries at 3 times the rate of male athletes in these same sports (IRR = 3.00). These findings are similar to IRRs previously reported[4] for male and female collegiate basketball and soccer players, which were approximately 3.6 and 2.8, respectively. However, ACL injury IRs did not differ between women and men for collision sports. The lack of a difference in ACL injury IRs between women and men in collision sports and between women in collision and contact sports may be partially explained by the lack of collision-sport participation by women. When participation was equal among women and men (contact sports), the greater ACL injury IR among women was evident. It is possible that not enough studies were available in which researchers investigated ACL injury incidence among both female and male collision athletes to detect a difference in the rates where one truly exists (ie, low statistical power).

In contrast, the ACL injury IRs for men in collision and contact sports differed (1.12/10 000 and 0.87/10 000 AEs, respectively). The sports included in these categories are similar because they require cutting and pivoting, which are dynamic maneuvers known to contribute to noncontact ACL injury mechanisms. Again, these combined findings further support the idea that neuromuscular deficits may contribute to the greater ACL injury IR among women. Although speculative, it was also possible that the men's decreased IR in collision sports compared with contact sports was due to direct-contact blows to the knee based on the nature of the sports.

Whereas our research may provide a robust estimate of sex differences in ACL injury IRs among sport types, it had limitations. The common metric of AE had to be estimated in some cases when exposure was provided in player-hours. This was necessary to include the maximum amount of data possible. As mentioned, we assumed that 2 player-hours were approximately equal to 1 AE, and we used this assumption to generate estimates of AEs. This assumption may have resulted in the overestimation or underestimation of exposure, depending on the sport. We used broad inclusion criteria to capture the greatest amount of information for generating these estimates. The included articles ranged in study quality, and the estimates are only as strong as the evidence on which they are based. However, we believed it was important to capture a wider range of studies to obtain a truer, more robust picture of ACL injury incidence among athletes. In addition, heterogeneity was relatively high (>75%) for the point estimates, indicating that populations that were grouped together may actually have differed. However, this was expected, as different sports have different demands that change the risk of sustaining an ACL injury. Moreover, heterogeneity for the rate ratios was low, and in some cases was 0%, indicating that the results were consistent and potentially generalizable. Given that female participation in collision sports was less prevalent than male participation, we included relatively few studies in which differences in ACL injury IRs between sexes were investigated. We could not control for variables known to contribute to ACL injury, including surface type, anticipation (anticipated event versus unanticipated event), or mechanism of injury (contact versus noncontact) because of a lack of information. Finally, we did not stratify by age or level of play, as those were not aims of this study.

To address these limitations, future researchers should report their findings in the most accurate units possible (player-hours) or should make both player-hours and AEs available to provide the opportunity for meta-analysis. Given that prospective designs allow for real-time data capture, investigators conducting future research in injury epidemiology should use prospective designs. Developing a standard and comprehensive checklist for criteria that should be met when performing or designing a prospective observational cohort study would provide a guide for researchers to achieve maximum study quality. This meta-analysis should be repeated in the future when more ACL injury data are available to permit comparisons of incidence rates among female and male athletes participating in collision and limited-contact sports. Finally, researchers should establish ACL injury IRs within each sport type while controlling for confounding variables, including age and level of play.

CONCLUSIONS

The incidence of ACL injury is associated with the nature of player-to-player contact inherent in the sport. Female athletes had greater ACL injury IRs than male athletes in contact and fixed-object HIRL sports. The latter sports category had the highest ACL injury IRs for both sexes, which might suggest the need for a new sport type to identify athletes at the highest risk of ACL injury. Future strategies aimed at reducing the risk of ACL injury may benefit from considering and integrating sport-related perturbation that mimics contact exposure to better equip athletes with prepreparatory and avoidance techniques.

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SUPPLEMENTAL MATERIAL

Supplemental Figures. Series of forest plots for incidence rate ratios.

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