Research in Sports Medicine, 20:157–179, 2012

ISSN: 1543-8627 print/1543-8635 online
DOI: 10.1080/15438627.2012.680633

REVIEW ARTICLES

Systematic Review: Annual Incidence of ACL Injury and Surgery in Various Populations

BASSAM MOSES
The Sports Clinic, University of Sydney, Australia

JOHN ORCHARD and JESSICA ORCHARD
School of Public Health, University of Sydney, Australia

Accurate documentation of injury incidence is critical for study of injury risk factors and prevention. Comparisons of published incidences of anterior cruciate ligament (ACL) injuries and surgical reconstructions are difficult, however, because of the variations in units. Some studies report absolute time-based denominators (such as annual incidence or incidence per 100,000 person years), whereas others report exposure-based denominators (such as incidence per 1,000 player hours or athlete exposures). We converted exposure-based units into annual incidences to compare various studies. National population studies show annual incidence rates of up to 0.05% per person per year in Australia. Professional athletes in basketball, soccer, and the other football codes report an annual incidence of 0.15%–3.7% in studies with at least a moderate sample size. Annual ACL incidence in amateur sporting groups was generally higher than the entire population but lower than among professional athletes. Converting incidence rates to annual units allowed better comparisons to be made between population rates across different studies.

KEYWORDS *anterior cruciate ligament, incidence, epidemiology*

Received 18 September 2011; accepted 26 March 2012.
Address correspondence to Bassam Moses, 111 Anzac Pde, Kensington, Australia. E-mail: bassam.moses@optusnet.com.au

INTRODUCTION

Anterior cruciate ligament (ACL) injuries of the knee are amongst the most common major injuries in sport. They are of particular concern in multidirectional team sports, such as basketball, netball, soccer, American football, Australian football, rugby league, and rugby union. Although there are numerous research publications detailing incidence rates of ACL injuries, comparison between studies is somewhat difficult because of the different methods of expressing incidence rates (Gianotti, Marshall, Hume, & Bunt, 2009; Hootman, Dick, & Agel, 2007; Orchard & Seward, 2002; Prodromos, Han, Rogowski, Joyce, & Shi, 2007; Walden, Hagglund, Magnusson, & Ekstrand, 2011). Injury surveillance, based on incidence rates, is a critical part of understanding risks for injury and, ultimately, injury prevention in sport (van Mechelen, Hlobil, & Kemper, 1992).

There are several ways of expressing incidence rates. The numerator should be defined according to what constitutes an injury, including whether new injuries only or new injuries and recurrences are included. With respect to the denominator, options include the following: (1) injuries per fixed absolute time period (e.g., annual incidence of injury); (2) injuries per athletic exposure (where an athletic exposure is a single match/training session, e.g., injuries per 1,000 athlete exposures); and (3) injuries per time period of actual exposure/play (e.g., injuries per 1,000 player hours). It should be noted that these different methods are related. For instance, sports where the participants have a higher exposure per year (in terms of hours played or number of games) will tend to have a greater annual incidence.

It is arduous however, to record athlete exposures and particularly exact exposure time by athlete. Some authors will do this for a specific study, often with short-term funding, in the interests of accuracy, but long-term injury surveillance systems (particularly national registers of ACL surgery) do not tend to have the resources to record athletic exposure consistently.

Superficially, a figure is more "accurate" if it takes into account exact exposure time. It follows that because the recording of exposure time is difficult, the studies that report injuries in terms of specific exposure generally have smaller sample sizes and hence the figures reported may have sampling errors and/or wide confidence intervals. At the other end of the scale, population studies provide rates of ACL injuries that are based on very large sample sizes but where exact exposure in terms of games or hours played is not calculated. Population rates also reflect the reality that athletes may actually expose themselves to multiple sporting activities over the course of a calendar year (i.e., by playing multiple sports) and also nonsporting mechanisms of ACL injury (i.e., traffic and workplace accidents).

Many, but not all, ACL injuries are managed with reconstructive surgery (Streich, Zimmermann, Bode, & Schmitt, 2011). Therefore, an incidence rate also needs to specify whether the numerator is the number of diagnosed

ACL injuries or the number of ACL surgeries. The total rate of ACL injuries obviously will be higher than the rate of ACL surgeries. Factors such as level and age of athlete, quality of health system, and propensity to recommend surgery are factors that determine whether someone with an ACL injury has surgery (Orchard, 2011). In the United States, for example, surgical management of ACL injuries is aggressively promoted (which may lead to higher reconstruction rates), but some patients are uninsured and cannot afford surgery (which may lead to lower reconstruction rates). In addition, not all ACL injuries are diagnosed (Janssen, Orchard, Driscoll, & van Mechelen, 2011) and therefore the "real" incidence rate of all (including undiagnosed) ACL injuries will be higher than the diagnosed ACL injuries.

The aim of this systematic review was to develop common units of ACL incidence that could be used to compare different study populations.

METHODS

A literature search was performed using Pubmed, Embase, and Sport Discus. The search terms used follow:

1. "Anterior Cruciate Ligament Injury" and "Incidence"
2. "Anterior Cruciate Ligament Injury" and "Epidemiology"
3. "Anterior Cruciate Ligament Reconstruction" and "Incidence"
4. "Anterior Cruciate Ligament Reconstruction" and "Epidemiology"

The searches yielded 1,798 results. Following review of the search results, including removal of duplicates and discarding of nonrelevant papers, 112 studies were found to report incidence data relating to either ACL injuries or ACL surgeries. The reference lists for these articles were checked, allowing several other articles to be included.

To be included a study needed to report the following:

- An annual incidence rate in terms of percentage of individuals who suffer an ACL injury (or have ACL surgery) per year;
- An annual incidence rate in a unit similar to injuries (or surgeries) per 100,000 person years, which could be directly converted to an annual percentage; or
- An incidence rate of injuries (or surgeries) per athlete exposure or 1,000 player hours, which could be included and converted into an annual incidence if either (a) the annual rate of athlete exposures/player hours was presented in the paper or (b) the relevant sporting competition had a fairly constant rate of annual exposures/player hours of exposure and an estimate could be made based on freely available data using Internet research.

From the original literature search, there were 37 papers that reported ACL injury incidence rates in a specific population (or populations) and 12 papers that reported ACL reconstruction rates in a specific population (or populations).

The studies provided 51 populations (18 general/national/mixed and 33 from specific sports) for which annual incidence of ACL injuries/surgeries could be reported or estimated using the methods above. The populations reviewed covered 16 countries, including some with sporting populations from an entire continent.

Studies generally were excluded because an incidence rate was not presented or there was not enough data available (about exposure) to create a valid annual incidence estimation. Studies that included cases of past or previous injuries were also excluded on this basis. Specific populations were also excluded from some papers (e.g., Prodromos et al., 2007) on the basis that they were based on short tournaments (<=1 week) and would probably not be reflective of the average annual risk for the population and therefore not accurately reflect annual incidence.

Confidence intervals for annual incidence were not calculated, as this would have required elimination of many further papers where the information required to calculate confidence intervals was not available.

Population annual incidence was selected as the common comparison unit. This was largely because it was easier to convert exact exposure incidence rates to population annual incidence rates than vice versa. When the incidence rates provided were expressed in units involving player hours or athlete exposures, the player hours or athlete exposures per year were calculated in order to convert to an annual incidence.

RESULTS

Annual incidences are presented both as annual percentage rates and per 100,000 person years in Tables 1–4, grouped according to the study population.

Population Studies at the National Level

There were 13 included studies with ACL injury/surgery data from national populations. As can be seen from Table 1, the annual national population incidence rates range from 0.01% to 0.05%. The median annual incidence was 0.03% for these countries.

Although these rates appear low, it is important to emphasise that Table 1includes persons of all ages (including babies and the elderly) and persons who do not engage in sporting activities. When the sub-rates of these populations are assessed for highly active groups (e.g. males aged

TABLE 1 Annual Incidence of ACL Injuries/Surgeries in a Population

Author	Measure	Location	Population	No. ACL Injuries	Years EXP	IR (% Per Year)	Per 100,000
GRANAN (Granan, Forssblad, Lind, & Engebretsen, 2009)	ACL surgeries	SWEDEN			5	0.03%	32
LIND (Lind, Menhert, & Pedersen, 2009)	ACL surgeries	DENMARK GERMANY			2.5	0.04%	38
						0.03%	32
KROGSGAARD (Krogsgaard, 2002)	ACL injuries	DENMARK	5,359,000	2500	1	0.05%	47
NIELSEN (Nielsen & Yde, 1991)	ACL injuries	DENMARK			1	0.03%	30
GRANAN (Granan et al., 2009)	ACL surgeries	NORWAY			1	0.03%	34
GRIFFIN (Griffin et al., 2000)	ACL injuries	USA	287,421,906	80,000	1	0.03%	28
CSINTALAN (Csintalan, Inacio, & Funahashi, 2008)	ACL surgeries	USA					
ALL					5	0.03%	30
Male					5	0.04%	41
Female					5	0.02%	18
LYMAN (Lyman et al., 2009)							
	ACL surgeries	NEW YORK STATE			10	0.04%	37
		US ESTIMATES			10	0.03%	29

(*Continued*)

TABLE 1 (Continued)

Author	Measure	Location	Population	No. ACL Injuries	Years EXP	IR (% Per Year)	Per 100,000
BELMONT (Belmont, Shawen, Mason, & Sladicka, 1999)	ACL surgeries	USA			7	0.05%	52
JANSSEN (Janssen et al., 2011)	ACL surgeries	AUSTRALIA			5	0.05%	52
GIANOTTI (Gianotti et al., 2009)	ACL surgeries	NZ			6	0.04%	37
JAMESON (Jameson et al., 2011)	ACL surgeries	UK			2	0.01%	14
CLAYTON (Clayton & Court-Brown, 2008)	ACL injuries	SCOTLAND			5	0.01%	8

TABLE 2 Annual Incidence of ACL Injuries/Surgeries in Military Populations

Author	Measure	Location	Population	ACL Injuries	Years EXP	IR (% Per Year)	Per 100,000
LAUDER (Lauder, Baker, Smith, & Lincoln, 2000)	ACL injuries	U.S. MILITARY					
TOTAL			13,861	1,289	6	1.55%	1,550
MALE			13,020	1,181	6	1.51%	1,511
FEMALE			841	108	6	2.14%	2,140
GWINN (Gwinn, Wilckens, McDevitt, Ross, & Kao, 2000)	ACL injuries	U.S. NAVY					
MALE			21,617	120	6	0.09%	93
FEMALE			2,884	39	6	0.23%	225
OWENS (Owens, Mountcastle, Dunn, DeBerardino, & Taylor, 2007)	ACL injuries	U.S. MILITARY					
TOTAL					6	0.37%	365
MALE					6	0.38%	379
FEMALE					6	0.30%	295
PETERSEN (Petersen, Call, Wood, Unger, & Sekiya, 2005)	ACL injuries	U.S. MILITARY	1,165	21	3	0.60%	601
	ACL surgeries		1,165	11	3	0.31%	314

TABLE 3 Annual Incidence of ACL Injuries/Surgeries in a Professional Sporting Group

Author	Measure	Location	Sport	Population	ACL injuries	Years exp	per 1000 AE	per 1000 PH	AE per year	PH per year	IR (% per year)	per 100,000
PRODROMOS (Prodromos et al., 2007)	ACL injuries	USA	BASKETBALL									
Female			WNBA				0.20		31	41	0.62%	620
Male			NBA				0.20		82	109	1.64%	1640
BRADLEY (Bradley, Klimkiewicz, Rytel, & Powell, 2002)	ACL injuries	USA	NFL	2500	209	5					1.67%	1672
WALDEN (Walden, Hagglund, Magnusson, et al., 2011)	ACL injuries	EUROPEAN MEN	PROFESSIONAL SOCCER	1367	43	9		0.06	36	54	0.32%	324
		SWEDISH MEN		652	20	9		0.06	30	45	0.27%	275
		SWEDISH WOMEN		310	15	9		0.41	26	39	1.60%	1599
ORCHARD (Orchard & Seward, 2002)	ACL injuries	AUSTRALIA	AFL			4	1.02		22	29	2.25%	2250
DEITCH (Deitch, Starkey, Walters, & Moseley, 2006)	ACL injuries	US	NBA	702	22	6	0.10		82	109	0.82%	820
			WNBA	443	14	6	0.40		31	41	1.24%	1240
O'CONNOR (O'Connor, 2011)	ACL injuries	AUSTRALIA	NRL	990	26	1	0.03		26	35	2.63%	2626

ROCHCONGAR (Rochcongar, Laboute, Jan, & Carling, 2009)	ACL injuries	FRANCE	MALE PROSOCCER	270	28	12			38	57	0.86%	864
FAUDE (Faude, Junge, Kindermann, & Dvorak, 2005)	ACL injuries	GERMANY	FEMALE BUNDES-LIGA SOCCER	165	10	1	0.07		22	29	0.15%	152
TEGNANDER (Tegnander, Olsen, Moholdt, Engebretsen, & Bahr, 2008)	ACL injuries	NORWAY	FEMALE 1ST DIVISION SOCCER	181	2	1					1.10%	1105
GIZA (Giza, Mithofer, Farrell, Zarins, & Gill, 2005)	ACL injuries	US	FEMALE SOCCER WUSA	202	8	2		0.09	21	32	0.28%	284
TROJIAN (Trojian & Collins, 2006)	ACL injuries	US	WNBA									
White						5	0.45		32	32	1.46%	1458
Non-White						5	0.07		32	32	0.23%	227
ROI (Roi, Nanni, Tavana, & Tencone, 2006)	ACL surgeries	ITALY	SERIE A SOCCER			1	1.08		34	51	3.67%	3672
WALDEN (Waldén, Aggland, et al. 2011)	ACL injuries	NORTH EUROPE	UEFA SOCCER			9		0.05	36	53	0.27%	266
		SOUTH EUROPE				9		0.11	37	56	0.62%	616

(Continued)

TABLE 3 (Continued)

Author	Measure	Location	Sport	Population	ACL injuries	Years exp	per 1000 AE	per 1000 PH	AE per year	PH per year	IR (% per year)	per 100,000
PUJOL (Pujol, Blanchi, & Chambat, 2007)	ACL injuries	FRANCE	PROFESSIONAL ALPINE SKIING	379	105	25					1.11%	1108
Male				191	52	25					1.09%	1089
Female				188	53	25					1.13%	1128
BROOKS (Brooks, Fuller, Kemp, & Reddin, 2005)	ACL injuries	ENGLISH	ENGLISH RUGBY CHAMPIONSHIP			2		0.42	22	29	1.23%	1232
VAUHNIK (Vauhnik et al., 2011)	ACL injuries	SLOVENIA	FEMALE PROFESSIONAL SPORTS	100	2	1		0.037			2.00%	2000
			BASKETBALL	41	3	1		0.09	30	24	7.32%	7317
			HANDBALL	258	6	1		0.047			2.33%	2326
			VOLLEYBALL	286	3	1		0.019			1.05%	1049
DALLALANA (Dallalana, Brooks, Kemp, & Williams, 2007)												
	ACL injuries	UK	ENGLISH RUGBY CHAMPIONSHIP	546	9	2		0.42	22	29	1.23%	1232
MEUFFELS (Meuffels & Verhaar, 2008)	ACL injuries	NETHERLANDS	NATIONAL COMPANY DANCERS	253	6	11					0.22%	216

LIEDERBACH (Liederbach, Dilgen, & Rose, 2008)	ACL injuries	USA	INTERNATIONAL BALLET COMPANIES	298	12	5	0.09		952	1269	0.81%	805
PERIERA (Periera, Nanni & Roi, 2003)	ACL injuries	EUROPE	PROFESSIONAL SOCCER	504	30	5					1.19%	1190
YANGUAS LEYES (Yanguas Leyes, Til Perez, & Cortes de Olano, 2011)	ACL injuries	SPAIN	PROFESSIONAL FEMALE SOCCER	166	11	3		0.29	27	40.5	1.17%	1175

TABLE 4 Annual Incidence of ACL Injuries/Surgeries in an Amateur Sporting Group

Author	Measure	Location	Sport	Population	ACL injuries	Years exp	per 1000 AE	per 1000 PH	AE per year	PH per year	IR (% per year)	per 100,000
AO (Ao, Tian, Cui, Hu, & Shi, 2000)	ACL injuries	CHINA	MULTIPLE	6810	32	3					0.16%	157
HOPPER (Hopper, Elliott, & Lalor, 1995)	ACL injuries	AUSTRALIA	AMATEUR NETBALL	11288	11	5					0.02%	19
PRODROMOS (Prodromos, et al., 2007)	ACL injuries	USA	**BASKETBALL**									
			COLLEGIATE [F]				0.29		28	38	0.82%	819
			COLLEGIATE [M]				0.08		29	38	0.23%	230
			HIGH SCHOOL [F]				0.09		29	39	0.27%	265
			HIGH SCHOOL [M]				0.21		30	39	0.62%	620
			SOCCER									
			COLLEGIATE [F]				0.32		19	25	0.61%	610
			COLLEGIATE [M]				0.12		19	25	0.22%	224
			LACROSSE									
			COLLEGIATE [F]				0.18		16	22	0.30%	295
			COLLEGIATE [M]				0.17		15	20	0.26%	260
			COLLEGIATE MALE FOOTBALL				0.08		11	15	0.09%	88
			COLLEGIATE RUGBY									
			COLLEGIATE [F]			4	0.36		18	24	0.65%	648
			COLLEGIATE [M]				0.02		10	13	0.02%	18

			WRESTLING									
			COLLEGIATE [F]		1	6	0.77		0.08		0.006%	6
			COLLEGIATE [M]		2	6	0.19		0.08		0.002%	2
SEIL (Seil, Rupp, Tempelhof, & Kohn, 1998)	ACL injuries	GERMANY	AMATEUR HANDBALL	186	5	1	0.24		20	26	0.47%	474
MYKELBUST (Myklebust, Maehlum, Holm, & Bahr, 1998)	ACL injuries	NORWAY	AMATEUR HANDBALL									
ALL					28	3	0.33		39	52	1.29%	1293
Female					23	3	0.56	0.31		52	1.62%	1618
Male					5	3	0.11	0.06		52	0.31%	314
OATES (Oates, Van Eenenaam, Briggs, Homa, & Sterett, 1999)	ACL injuries	USA	ALPINE SKIING EMPLOYEES	4748	19	3	0.02				0.13%	133
VIOLA (Viola, Steadman, Mair, Briggs, & Sterett, 1999)												
ALL	ACL injuries	USA	ALPINE SKIING EMPLOYEES	7155	31	5					0.09%	87
MALE				4537	21	5					0.09%	93
FEMALE				2618	10	5					0.08%	76
HOOTMAN (Hootman et al., 2007)	ACL injuries	USA	**NCAA**									

(*Continued*)

TABLE 4 (Continued)

Author	Measure	Location	Sport	Population	ACL injuries	Years exp	per 1000 AE	per 1000 PH	AE per year	PH per year	IR (% per year)	per 100,000
			MEN'S BASEBALL		56	16	0.02		46	62	0.09%	92
			MEN'S BASKETBALL		167	16	0.07		29	38	0.20%	201
			WOMEN'S BASKETBALL		498	16	0.23		28	38	0.65%	650
			WOMEN'S FIELD HOCKEY		53	16	0.07		20	26	0.14%	138
			MEN'S FOOTBALL		2159	16	0.18		11	15	0.20%	198
			MEN'S ICE HOCKEY		78	16	0.06		33	44	0.20%	198
			WOMEN'S ICE HOCKEY		3	4	0.03		29	39	0.09%	88
			MEN'S LACROSSE		131	16	0.12		15	20	0.18%	183
			WOMEN'S LACROSSE		145	16	0.17		16	22	0.28%	279
			MEN'S SOCCER		168	16	0.09		19	25	0.17%	168
			WOMEN'S SOCCER		411	16	0.28		19	25	0.53%	534
			WOMEN'S SOFTBALL		129	16	0.08		44	59	0.35%	353
			WOMEN'S VOLLEYBALL		142	16	0.09		31	41	0.28%	275
			MEN'S WRESTLING		147	16	0.11		42	57	0.47%	467
			MEN'S SPRING FOOTBALL		379	16	0.33		1	1	0.03%	33

LE GALL (Le Gall, Carling, & Reilly, 2008)	ACL injuries	FRANCE	FEMALE AMATEUR SOCCER	119	10	8	0.01	30	40	0.04%	36
ROCHCONGAR (Rochcongar et al., 2009)											
ALL	ACL injuries	FRANCE	AMATEUR SOCCER	44366	699	12				0.13%	131
District				40106	568	12				0.12%	118
Regional				3390	103	12				0.25%	253
JANSSEN (Janssen et al., 2011)	ACL surgeries	AUSTRALIA	SKIING			5				0.42%	417
			SOCCER			5				0.21%	211
			AUSSIE RULES			5				0.27%	273
			RUGBY LEAGUE & UNION			5				0.26%	255
			NETBALL			5				0.19%	188
			TOUCH FOOTBALL			5				0.16%	157
			BASKETBALL			5				0.11%	109
			MOTORCYCLING			5				0.07%	65
			ALL			5				0.06%	61
MORODER (Moroder, Runer, Hoffel, Frick, Resch & Taube, 2011)	ACL injuries	AUSTRIA	SNOWKITING	80	1	1				1.25%	1250

15–40) the rates are substantially higher (Gianotti, et al., 2009; Janssen, et al., 2011). Where reported, national population annual ACL incidence for young males were higher than the comparative rates for young females.

Studies of Particular Sporting/Activity Groups

Military Groups

There were four included studies with ACL injury/surgery data from U.S. military groups. The annual incidence figures calculated from these studies, presented in Table 2, range from 0.30% to 2.14%. As can be seen, these rates are much higher than the U.S. population ratios in Table 1 and are broadly comparable to the figures for professional/elite sports shown in Table 3.

Professional Sporting Groups

The annual incidence of ACL injuries/surgeries from the 15 included studies of professional sporting groups is shown in Table 3. As for military populations, the annual ACL injury rates in professional sport (ranging from 0.15% to 3.67%) are substantially higher than national population rates.

Studies were considered to relate to professional sporting groups if they involved paid athletes/performers or elite level athletes/performers. Therefore, the studies involving professional and elite dance companies were included in this section. Conversely, studies of ski resort employees were included in the amateur section.

Annual injury incidence rates were calculated from a range of included studies of amateur sporting groups. As noted above, this group includes two studies of ski resort employees. These studies did not examine injuries involving competitive professional skiing, but rather they looked at work-related injuries. The rates are quite variable (Table 4) but are generally higher than the reported national population rates but lower than the rates for professional/elite athletes.

The annual ACL injury incidence reported rates for professional athletes (ranging from 0.15% to 3.67% in studies of at least moderate sample size) are substantially higher than national population rates (median rate of 0.03%). It appears that multidirectional team sports (e.g., basketball, football codes, netball) that have the highest rates of ACL injuries give rise to specific publications, whereas sports that probably have much lower rates of ACL injuries (e.g., water sports, tennis, cricket) do not tend to give rise to publications. The annual ACL injury incidence reported rates for amateur athletes (ranging from 0.03% to 1.62% in studies of at least moderate sample size) are generally lower than the professional sport incidence rates but higher than national population rates.

DISCUSSION

There are many studies that have reported incidence of ACL injuries and surgeries. An adequate number were able to have units converted into annual incidences to allow comparison between studies. It was more difficult to determine annual incidence rates where the units were expressed in either player hours or athlete exposures. Athlete exposures or playing hours per year were required (or had to be accurately estimated) in order to make calculations. Fortunately, the majority of professional sports bodies had data on their websites regarding exposure (in terms of games and/or hours of play) for the years reported in the specific period of the study. In certain cases, such as with collegiate sports in the United States, extensive calculations of games played across hundreds of colleges were used to determine a significant average of athlete exposures per year.

National ACL injury or surgery incidence rates at population levels are available for over half a dozen countries, particularly in Scandinavia and Australasia. The national rates reported for most countries, including Scandinavian and continental European countries, New Zealand, and the United States are fairly similar (annual incidence rates of 0.03%–0.04%). Australia had only one study that reported a higher incidence rate than the other countries (0.05% annual incidence), whereas the studies from the United Kingdom reported lower rates (0.01%–0.02% annual incidence).

Further research is required to determine the underlying reasons for differences between countries. The most obvious explanation for different national population rates relates to variations in sporting exposure. Countries that have high annual rates of participation in the various forms of football, snow sports, and court sports will tend to have higher rates of ACL injury. Climate may play a role (Orchard, Chivers, Aldous, Bennell, & Seward, 2005), including in terms of exposure, in that countries with temperate weather will perhaps have longer playing seasons leading to a higher number of exposure hours per year. When comparing ACL surgery rates (as opposed to ACL incidence rates), the health systems of countries are relevant (Magnussen et al., 2010), in that systems that encourage and/or fund surgery more readily may lead to a higher percentage of ACL injuries being surgically treated (Orchard, 2011). Ideally, more countries will take up the Scandinavian initiative to fund an annual national ACL registry, just as many countries have followed the Scandinavian lead with respect to joint replacement registries.

It has been established that females have a higher incidence rate of ACL injury than males when exposed to the same sport (Arendt, Agel, & Dick, 1999; Hootman et al., 2007; Myklebust et al., 1998; Prodromos et al., 2007; Walden, Hagglund, Magnusson & Ekstrand, 2011). At a population level, however, males generally have a higher annual ACL injury incidence than females, which is almost certainly due to an exposure bias in that males are more likely to play higher risk sports, especially the various forms of football.

Annual incidence rates for various sporting groups are much higher than the national population rates, particularly at professional/elite levels. This is because the highest risk section of the population (i.e., those who play multidirectional sports) has been specifically studied. Professional and elite squads also generally have a higher rate of injuries/surgeries than amateur squads, which is an interesting finding given that it is thought that poor movement coordination could be a risk factor for ACL injury (Myer, Ford, & Hewett, 2005).

There are various possible explanations for the higher observed rates in professional populations (compared with amateur). Professional and elite athletes are more likely to have an ACL injury diagnosed, as they require knee stability to continue to perform. In addition, there is a greater likelihood of reconstructive surgery being required in high-level athletes. At higher levels of play there is presumably greater force on the knee joint due to an increased pace/intensity of play, the need for more rapid change of direction, and less time to anticipate what the (more skilled) opponents will do. Finally, it is likely that professional and elite athletes play more games annually and train for longer numbers of hours than amateur athletes, increasing exposure to injury.

Although poor knee coordination has been proposed as a risk factor for ACL injuries (Myer et al., 2005), the lower coordination of amateur players does not appear to outweigh the greater intensity and exposure of high-level play, meaning that the annual rate of ACL injury/surgery appears to be consistently higher in professional/elite players.

It is also apparent that within the professional sporting groups there are differences in incidence rates. The football codes generally have a higher incidence of ACL injury compared with other professional sports. There may be several factors responsible for this difference: multidirectional movement, the potential for player-to-player contact at high speed, and play on grass surfaces using cleated footwear creating high shoe–surface traction.

We recommend that future studies of ACL injury incidence include in the report an annual incidence of injury (expressed as a percentage or in terms of injuries per 100,000 person years). If exact exposure data (in terms of athlete exposures or player hours) is also available, ideally this could be included as well, although it may be many years until national ACL surveillance systems are able to include annual updates of exposure data. Including all of this information, where possible, allows maximum comparability between studies and also allows exposure bias to be taken into account.

Consistent methods of reporting ACL injury incidence will help us further understand the risk factors and evaluate success of prevention programs, according to the van Mechelen paradigm (van Mechelen et al., 1992). Uniform reporting of both ACL injury and surgery rates would allow simple and direct comparisons of such data. This would make it easier to identify differences in injury rates amongst demographic groups, different geographical locations, climate types, playing surfaces, different sports, levels of skill, and training. This ability to compare differences in incidence would help identify predisposing factors that lead to ACL injuries.

CONCLUSION

Reporting of ACL injury using common units, such as annual incidences, would allow easier comparison of incidence rates between population and sporting groups. The results of this literature review show that incidence rates in the general population are lower than those of the athletic population. The review does not support the view that males and professional athletes have a lower annual rate of injury as a result of better coordinated movement patterns, although exposure bias may account for the higher reported annual rates in males and elite athletes. Further research is required to determine the causes for the different injury rates seen in different sports and populations. Despite a large number of research publications that detail the incidence rates of ACL injury, comparison is difficult due to the varied methods of reporting incidence rates. It is suggested that studies that use a denominator of player hours or athlete exposures to report injury rates should also include an annual incidence rate to allow comparison with other studies. Conformity in reporting methods for ACL injury incidence would assist recognition of risk factors for ACL injury and eventually prevention of these injuries.

REFERENCES

Ao, Y. F., Tian, D. X., Cui, G. Q., Hu, Y. J., & Shi, H. F. (2000). Epidemiological investigation of anterior cruciate ligament injury in athletes. *Sports Science/Tiyu Kexue*, *20*(4), 47–48; 88.

Arendt, E. A., Agel, J., & Dick, R. (1999). Anterior cruciate ligament injury patterns among collegiate men and women. *Journal of Athletic Training*, *34*(2), 86–92.

Belmont, P. J., Jr., Shawen, S. B., Mason, K. T., & Sladicka, S. J. (1999). Incidence and outcomes of anterior cruciate ligament reconstruction among U.S. Army aviators. *Aviation, Space, and Environmental Medicine*, *70*(4), 316–320.

Bradley, J. P., Klimkiewicz, J. J., Rytel, M. J., & Powell, J. W. (2002). Anterior cruciate ligament injuries in the National Football League: Epidemiology and current treatment trends among team physicians. *Arthroscopy: The Journal* *of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association*, *18*(5), 502–509. doi:10.1053/jars.2002.30649

Brooks, J.H.M., Fuller, C. W., Kemp, S.P.T., & Reddin, D. B. (2005). Epidemiology of injuries in English professional rugby union: Part 1 match injuries. *British Journal of Sports Medicine*, *39*(10), 752–756.

Clayton, R. A., & Court-Brown, C. M. (2008). The epidemiology of musculoskeletal tendinous and ligamentous injuries. *Injury*, *39*(12), 1338–1344. doi:10.1016/j.injury.2008.06.021

Csintalan, R. P., Inacio, M. C., & Funahashi, T. T. (2008). Incidence rate of anterior cruciate ligament reconstructions. *The Permanente Journal*, *12*(3), 17–21.

Dallalana, R. J., Brooks, J. H., Kemp, S. P., & Williams, A. M. (2007). The epidemiology of knee injuries in English Professional Rugby Union. *The American Journal of Sports Medicine*, *35*(5), 818–830. doi:10.1177/0363546506296738

Deitch, J. R., Starkey, C., Walters, S. L., & Moseley, J. B. (2006). Injury risk in professional basketball players: A comparison of Women's National Basketball Association and National Basketball Association athletes. [Comparative Study]. *The American Journal of Sports Medicine*, *34*(7), 1077–1083. doi:10.1177/0363546505285383

Faude, O., Junge, A., Kindermann, W., & Dvorak, J. (2005). Injuries in female soccer players: A prospective study in the German National League. [Research Support, Non-U.S. Gov't]. *The American Journal of Sports Medicine*, *33*(11), 1694–1700. doi:10.1177/0363546505275011

Gianotti, S. M., Marshall, S. W., Hume, P. A., & Bunt, L. (2009). Incidence of anterior cruciate ligament injury and other knee ligament injuries: A national population-based study. *Journal of Science and Medicine in Sport/Sports Medicine Australia*, *12*(6), 622–627. doi:10.1016/j.jsams.2008.07.005

Giza, E., Mithofer, K., Farrell, L., Zarins, B., & Gill, T. (2005). Injuries in women's professional soccer. *British Journal of Sports Medicine*, *39*(4), 212–216; discussion 212–216. doi:10.1136/bjsm.2004.011973

Granan, L. P., Forssblad, M., Lind, M., & Engebretsen, L. (2009). The Scandinavian ACL registries 2004–2007: Baseline epidemiology. [Research Support, Non-U.S. Gov't]. *Acta Orthopaedica*, *80*(5), 563–567. doi:10.3109/17453670903350107

Griffin, L. Y., Agel, J., Albohm, M. J., Arendt, E. A., Dick, R. W., Garrett, W. E., . . . Wojtys, E. M. (2000). Noncontact anterior cruciate ligament injuries: Risk factors and prevention strategies. [Review]. *The Journal of the American Academy of Orthopaedic Surgeons*, *8*(3), 141–150.

Gwinn, D. E., Wilckens, J. H., McDevitt, E. R., Ross, G., & Kao, T. C. (2000). The relative incidence of anterior cruciate ligament injury in men and women at the United States Naval Academy. *The American Journal of Sports Medicine*, *28*(1), 98–102.

Hootman, J. M., Dick, R., & Agel, J. (2007). Epidemiology of collegiate injuries for 15 sports: Summary and recommendations for injury prevention initiatives. [Review]. *Journal of Athletic Training*, *42*(2), 311–319.

Hopper, D., Elliott, B., & Lalor, J. (1995). A descriptive epidemiology of netball injuries during competition: A five year study. [Research Support, Non-U.S. Gov't]. *British Journal of Sports Medicine*, *29*(4), 223–228.

Jameson, S. S., Dowen, D., James, P., Serrano-Pedraza, I., Reed, M. R., & Deehan, D. (2011). Complications following anterior cruciate ligament reconstruction in the English NHS. *The Knee*. doi:10.1016/j.knee.2010.11.011

Janssen, K. W., Orchard, J. W., Driscoll, T. R., & Van Mechelen, W. (2011). High incidence and costs for anterior cruciate ligament reconstructions performed in Australia from 2003–2004 to 2007–2008: Time for an anterior cruciate ligament register by Scandinavian model? *Scandinavian Journal of Medicine & Science in Sports*. [Epub]. doi:10.1111/j.1600-0838.2010.01253.x

Krogsgaard, M. R. (2002). [The anterior cruciate ligament]. [Review]. *Ugeskrift for laeger*, *164*(9), 1208–1214.

Lauder, T. D., Baker, S. P., Smith, G. S., & Lincoln, A. E. (2000). Sports and physical training injury hospitalizations in the army. [Research Support, U.S. Gov't, Non-P.H.S.]. *American Journal of Preventive Medicine*, *18*(3 Suppl.), 118–128.

Le Gall, F., Carling, C., & Reilly, T. (2008). Injuries in young elite female soccer players: An 8-season prospective study. *The American Journal of Sports Medicine*, *36*(2), 276–284. doi:10.1177/0363546507307866

Liederbach, M., Dilgen, F. E., & Rose, D. J. (2008). Incidence of anterior cruciate ligament injuries among elite ballet and modern dancers: A 5-year prospective study. [Comparative Study Research Support, Non-U.S. Gov't]. *The American Journal of Sports Medicine*, *36*(9), 1779–1788. doi:10.1177/0363546508323644

Lind, M., Menhert, F., & Pedersen, A. B. (2009). The first results from the Danish ACL reconstruction registry: Epidemiologic and 2 year follow-up results from 5,818 knee ligament reconstructions. *Knee Surgery, Sports Traumatology, Arthroscopy: Official Journal of the ESSKA*, *17*(2), 117–124. doi:10.1007/s00167-008-0654-3

Lyman, S., Koulouvaris, P., Sherman, S., Do, H., Mandl, L. A., & Marx, R. G. (2009). Epidemiology of anterior cruciate ligament reconstruction: Trends, readmissions, and subsequent knee surgery. [Research Support, U.S. Gov't, P.H.S.]. *The Journal of Bone and Joint Surgery. American Volume*, *91*(10), 2321–2328. doi:10.2106/JBJS.H.00539

Magnussen, R., Granan, L., Dunn, W., Amendola, A., Andrish, J., Brophy, R., . . . Engebretsen, L. (2010). Cross-cultural comparison of patients undergoing ACL reconstruction in the United States and Norway. *Knee Surgery, Sports Traumatology and Arthroscopy*, *18*(1), 98–105.

Meuffels, D. E., & Verhaar, J. A. (2008). Anterior cruciate ligament injury in professional dancers. *Acta Orthopaedica*, *79*(4), 515–518. doi:10.1080/17453670710015517

Moroder, P., Runer, A., Hoeffelner, T., Frick, N., Resch, H., Tauber, M. (2011). A prospective study of snowkiting injuries. *The American Journal of Sports Medicine*, *39*(7), 1534–1540.

Myer, G. D., Ford, K. R., & Hewett, T. E. (2005). The effects of gender on quadriceps muscle activation strategies during a maneuver that mimics a high ACL injury risk position. *Journal of Electromyography & Kinesiology*, *15*(2), 181–189.

Myklebust, G., Maehlum, S., Holm, I., & Bahr, R. (1998). A prospective cohort study of anterior cruciate ligament injuries in elite Norwegian team handball. [Research Support, Non-U.S. Gov't]. *Scandinavian Journal of Medicine & Science in Sports*, *8*(3), 149–153.

Nielsen, A. B., & Yde, J. (1991). Epidemiology of acute knee injuries: A prospective hospital investigation. [Research Support, Non-U.S. Gov't]. *The Journal of Trauma*, *31*(12), 1644–1648.

O'Connor, D. (2011). NRL injury report. *Sport Health*, *29*(1), 17–25.

Oates, K. M., Van Eenenaam, D. P., Briggs, K., Homa, K., & Sterett, W. I. (1999). Comparative injury rates of uninjured, anterior cruciate ligament-deficient, and reconstructed knees in a skiing population. [Comparative Study Research Support, Non-U.S. Gov't]. *The American Journal of Sports Medicine*, *27*(5), 606–610.

Orchard, J. W. (2011). Why does Australia have a higher rate of knee reconstruction surgery than New Zealand (and Scandinavia) and what can we do about it? *Journal of Science and Medicine in Sport*, *14*(4), 276–277.

Orchard, J., & Seward, H. (2002). Epidemiology of injuries in the Australian Football League, seasons 1997–2000. [Research Support, Non-U.S. Gov't]. *British Journal of Sports Medicine*, *36*(1), 39–44.

Orchard, J. W., Chivers, I., Aldous, D., Bennell, K., & Seward, H. (2005). Rye grass is associated with fewer non-contact anterior cruciate ligament injuries than Bermuda grass. *British Journal of Sports Medicine*, *39*(10), 704–709.

Owens, B. D., Mountcastle, S. B., Dunn, W. R., DeBerardino, T. M., & Taylor, D. C. (2007). Incidence of anterior cruciate ligament injury among active duty U.S. military servicemen and servicewomen. *Military Medicine*, *172*(1), 90–91.

Pereira, M. T., Nanni, G., Roi, G. S. (2003). Epidemiology of anterior cruciate ligament injuries in professional football players. *Archivos de Medicina del Deporte*, *20*(96), 299–303.

Peterson, S. N., Call, M. H., Wood, D. E., Unger, D. V., Sekiya, J. K. (2005). Injuries in Naval Special Warfare Sea, Air, and Land Personnel: Epidemiology and surgical management. *Operative Techniques in Sports Medicine*, *13*(3), 131–135.

Prodromos, C. C., Han, Y., Rogowski, J., Joyce, B., & Shi, K. (2007). A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury-reduction regimen. [Meta-Analysis Review]. *Arthroscopy: The Journal of Arthroscopic & Related Surgery: Official Publication of the Arthroscopy Association of North America and the International Arthroscopy Association*, *23*(12), 1320–1325 e1326. doi:10.1016/j.arthro.2007.07.003

Pujol, N., Blanchi, M. P., & Chambat, P. (2007). The incidence of anterior cruciate ligament injuries among competitive Alpine skiers: A 25-year investigation. *The American Journal of Sports Medicine*, *35*(7), 1070–1074. doi:10.1177/0363546507301083

Rochcongar, P., Laboute, E., Jan, J., & Carling, C. (2009). Ruptures of the anterior cruciate ligament in soccer. *International Journal of Sports Medicine*, *30*(5), 372–378. doi:10.1055/s-0028–1105947

Roi, G. S., Nanni, G., Tavana, R., & Tencone, F. (2006). Prevalence of anterior cruciate ligament reconstructions in professional soccer players. *Sport Sciences for Health*, *1*(3), 118–121.

Seil, R., Rupp, S., Tempelhof, S., & Kohn, D. (1998). Sports injuries in team handball. A one-year prospective study of sixteen men's senior teams of a superior nonprofessional level. [Comparative Study]. *The American Journal of Sports Medicine*, *26*(5), 681–687.

Streich, N. A., Zimmermann, D., Bode, G., & Schmitt, H. (2011). Reconstructive versus non-reconstructive treatment of anterior cruciate ligament insufficiency. A retrospective matched-pair long-term follow-up. *International Orthopaedics*, *35*(4), 607–613.

Tegnander, A., Olsen, O. E., Moholdt, T. T., Engebretsen, L., & Bahr, R. (2008). Injuries in Norwegian female elite soccer: A prospective one-season cohort study. [Research Support, Non-U.S. Gov't]. *Knee Surgery, Sports Traumatology, Arthroscopy: Official Journal of the ESSKA*, *16*(2), 194–198. doi:10.1007/s00167-007-0403-z

Trojian, T. H., & Collins, S. (2006). The anterior cruciate ligament tear rate varies by race in professional women's basketball. *The American Journal of Sports Medicine*, *34*(6), 895–898. doi:10.1177/0363546505284384

van Mechelen, W., Hlobil, H., & Kemper, H. (1992). Incidence, severity, aetiology and prevention of sports injuries: A review of concepts. *Sports Medicine*, *14*(2), 82–99.

Vauhnik, R., Morrissey, M. C., Rutherford, O. M., Turk, Z., Pilih, I. A., & Perme, M. P. (2011). Rate and risk of anterior cruciate ligament injury among sportswomen in Slovenia. *Journal of Athletic Training*, *46*(1), 92–98. doi:10.4085/1062–6050–46.1.92

Viola, R. W., Steadman, J. R., Mair, S. D., Briggs, K. K., & Sterett, W. I. (1999). Anterior cruciate ligament injury incidence among male and female professional alpine skiers. *The American Journal of Sports Medicine*, *27*(6), 792–795.

Walden, M., Hagglund, M., Magnusson, H., & Ekstrand, J. (2011). Anterior cruciate ligament injury in elite football: A prospective three-cohort study. *Knee Surgery, Sports Traumatology, Arthroscopy: Official Journal of the ESSKA* [Research Support, Non-U.S. Gov't], *19*(1), 11–19.

Waldén, M., Hagglund, M., Orchard, J., Kristenson, K., & Ekstrand, J. (2011). Regional differences in injury incidence in European professional football. *Scandinavian Journal of Medicine and Science in Sports*. [November 3 Epub before print]. doi: 10.111/j.1600-0838.2011.01409.x

Yanguas Leyes, J., Til Perez, L., Cortes de Olano, C. (2011). Anterior cruciate ligament injury in female soccer. Epidemiology of three seasons. *Apunts. Medicina de l'Esport*, *46*(171), 137–143.