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Sex Differences in Posterior Cruciate Ligament Injuries

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BACKGROUND: Acute tears of the posterior cruciate ligament (PCL) have been more commonly reported in males than females, with males constituting between 60 and 84% of isolated and combined PCL injuries. However, there is a paucity of studies comparing the injury patterns between males and females. This study aimed to evaluate the differences in patterns of isolated PCL tears and associated injuries between males and females on magnetic resonance imaging (MRI).
METHODS: Patients with PCL tears were identified through an institutional database. Two musculoskeletal imaging radiologists independently reviewed each case to describe injury patterns as well as the presence and severity of concurrent injuries. After applying exclusion criteria, male and female cohorts were compared for differences in injury patterns and the presence of concurrent injuries. Linear regression analysis was performed to assess for differences in injury patterns related to age.
RESULTS: A search yielded 322 consecutive patients with PCL injury. After reviewing MRI exams and applying exclusion criteria, the cohorts included 79 patients (21 female and 58 male). Overall, females with PCL tears were more likely to sustain concurrent injuries to the posteromedial corner (71.4% vs. 25.9%, $p<0.001$), anterior cruciate ligament (14.3% vs. 0%, $p=0.003$), partial injury to the medial collateral ligament (23.8% vs. 6.9%, $p=0.037$), and lateral meniscus (38.1% vs. 3.5%, $p<0.001$). Comparison of patients with Grade 3 PCL injuries showed that this type of injury occurred at a greater age in females when compared to males (46.0±22.1 vs. 32.3±13.5, $p=0.019$). Regression analysis between age and injury pattern in patients with Grade 3 PCL tears revealed significant findings only in female patients, with a positive correlation between age and distal location of the PCL tear ($R^2 = 0.5937$, $p=0.003$). We also observed significant negative correlations between age and associated injuries of the ACL ($R^2 = 0.3623$, $p=0.038$), and lateral retinaculum ($R^2 = 0.3325$, $p=0.049$).
CONCLUSION: We observed significant sex differences in the number and type of accompanying injuries with acute PCL injuries. Complete PCL injuries were found to occur at a greater age in females, with an age-dependent distribution of PCL injury location and number of accompanying injuries. Further studies are needed to understand the role of these findings in the treatment and outcomes after PCL injury.

INTRODUCTION

Isolated posterior cruciate ligament (PCL) tears are uncommon injuries, with a reported rate of 2 per 100,000.[1] Acute tears of the PCL have been more commonly reported in males than females, with males constituting between 60 and 84% of isolated and combined PCL injuries [2-6]. This is in contrast to anterior cruciate ligament (ACL) injuries, where females have been shown to be more prone to suffer from these injuries [7-9]. Prior studies comparing

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males and females with ACL injuries have reported differences in injury patterns based on magnetic resonance imaging (MRI). Fayad et al reported that males had more concurrent bony and soft tissue injuries, reporting an increased rate of injuries to the medial meniscus, lateral collateral ligament and PCL when compared to females with ACL injuries, stressing the importance of awareness and treatment of sex-based differences in injury patterns [10].

While ACL and PCL injuries have different mechanisms, the cruciate ligaments both play critical roles in stabilization of the knee. [11] Although females have a lower overall prevalence of PCL tears, no studies currently exist comparing patterns of associated injury to additional knee structures between males and females. MRI has been established as a highly useful method of accurately evaluating the integrity of the PCL, with a sensitivity between 96 and 100% and a negative predictive value approaching 100 % [12–15]. Hence, the purpose of this study is to describe the differences in patterns of PCL tears and associated injuries between males and females, based on associated meniscal, ligamentous, and bony injuries on MRI. Our hypothesis was that there would be significant differences in the rates and types of injury patterns between male and female patients with PCL tears.

MATERIALS AND METHODS

Patients

After obtaining approval from the Institutional Review Board, an institutional database of MRI reports and health records between 1995 and 2016 was searched to identify patients with PCL tears. Exclusion criteria were the following: (1) inadequate, absent, or duplicate imaging, (2) skeletal immaturity defined by the presence of open physes, (3) findings consistent with chronic rather than acute PCL injury defined by the absence of soft tissue edema, joint effusion, or osseous contusion based on review of MR images, (4) and knees with a history of prior surgery.

Imaging Studies

All MRI examinations were performed at 1.5 T or 3 T MRI with a dedicated surface coil (Siemens Medical Solutions USA, Inc., Malvern, PA, USA and GE Healthcare, Chicago, IL, USA). All images were reviewed and confirmed to be of diagnostic quality by musculoskeletal radiologists. Imaging sequences and parameters were the following:

- Coronal T1-weighted: TR 480–620 ms, TE 15–17 ms, flip angle 90, NEX 1, matrix size 448 × 384, FOV16 cm, slice thickness/gap 4/10
- Sagittal T2-weighted fat-saturated: TR 3700–4400 ms, TE 35–48 ms, flip angle 90, NEX 1–2, matrix size 320–288, FOV 15–16 cm, slice thickness/gap 3/10
- Coronal T2-weighted fat-saturated: TR 3300–3800 ms, TE 45–52 ms, flip angle 90, NEX 1, matrix size 320–288, FOV 16 cm, slice thickness/gap 4/10
- Sagittal proton density: TR 2000–2600 ms, TE 25–27 ms, flip angle 90, NEX 1, matrix size 320–320, FOV 15–16 cm, slice thickness/gap 3/10
- Axial T2-weighted fat-saturated: TR 3600–4900 ms, TE50–55 ms, flip angle 90, NEX 2, matrix size 320–256, FOV 15–16 cm, slice thickness/gap 3/10

MRI review

Two musculoskeletal imaging fellowship-trained radiologists with 6 and 7 years of experience (C.Y.C. and F.J.S.) independently reviewed each case for injury of the PCL. PCL injuries were categorized into three grades: grade 1 indicating sprain or low-grade partial tear, grade 2 as high-grade partial tear, and grade 3 representing complete tear or avulsion. Sprain/low-grade partial tear were defined as abnormal thickening (≥ 7 mm) without a fluid gap or attenuation and T2 hyperintense signal to normal ligament involving less than 50% of ligament fibers. High-grade partial tear was defined as discontinuity of and fluid signal gap between tendon fibers involving 50 to <100% of ligament fibers, and complete tear was defined as tear of the entirety of the ligament. The location of the PCL tear was classified into proximal, middle, or distal third of the involved ligament (**Figure 1**).

In addition to the PCL, each ligament, tendon, and muscle was graded as normal, partly injured, or completely injured. Each structure was defined as injured if it was thickened or attenuated and T2 hyperintense to normal ligament/tendon fibers but hypointense to fluid, partially discontinuous with a Fluid signal intensity gap, or completely discontinuous with a fluid signal gap.

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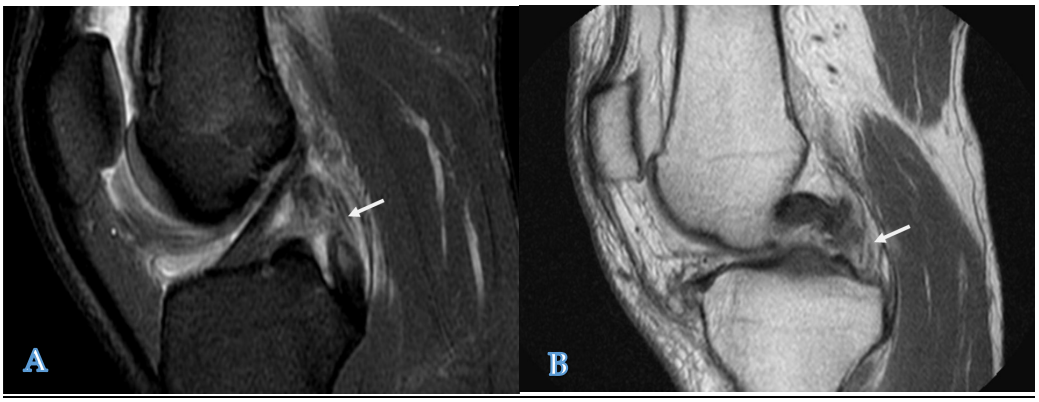

Figure 1. Sagittal images demonstrate differences in PCL tear location. 1a) T2 weighted sagittal view of the knee demonstrates a mid-substance PCL tear (arrow); 1b) T1 weighted sagittal view of the knee shows a distal PCL tear (arrow).

Table 1. Each additional structure that was assessed and graded for concurrent injury is listed.

Anterior cruciate ligament (ACL)
Medial collateral ligament (MCL)
Lateral collateral ligament (LCL)
Medial meniscus
Lateral meniscus
Medial gastrocnemius muscle
Lateral gastrocnemius muscle
Medial patellar retinaculum
Lateral patellar retinaculum
Posterolateral corner (PMC)
Posteromedial corner (PLC)
Presence of chondral fractures
Presence of subchondral edema

Cartilage and menisci were defined as injured if there was a fluid signal intensity gap in the normal structure. Edema was defined by increased T2 signal on fluid sensitive sequences with corresponding decreased T1 signal. Fracture was defined by cortical discontinuity or subchondral linear low T1 signal with surrounding increased T2 signal. For statistical analysis, discrepant reads were reconciled by using the more senior radiologist's interpretation (CYC).

Statistical analysis

PCL injuries of all types were compared between males and females in terms of their demographic characteristics (age), PCL injury characteristics (PCL tear location, mechanism of injury), and accompanying injuries of the knee (**Table 1**). Pearson's Chi-square test was used to determine if there was a significant difference between frequency of categorical variables.

A subgroup of patients with complete (grade III) PCL injuries were compared by sex using the same parameters, in terms of their demographic characteristics (age), PCL injury characteristics (PCL tear location, mechanism of injury), and accompanying injuries of the knee (**Table 1**).

After identifying age as a significant factor between male and female patients with PCL injuries, we analyzed the influence of the age on the PCL injury characteristics (PCL tear location, mechanism of injury), and accompanying injuries of the knee using linear regression analysis.

P Values <0.05 were considered as statistically significant. All statistical analysis was performed in SPSS (SPSS version 18.0, IBM Corp., Armonk, NY).

RESULTS

Cohort Characteristics

A search of our institutional database of MRI reports and electronic health records between 1995 and 2016 yielded 322 consecutive patients. 151 patients with inadequate, absent, or duplicate imaging were excluded, followed by 3 patients with skeletal immaturity defined by the presence of open physes, 4 patients with findings consistent with chronic rather than acute PCL injury defined by the absence of soft tissue edema, joint effusion, or osseous contusion based on review of MR images, and 85 patients with prior knee surgery.

The resultant group included 79 patients (21 female and 58 male). Of all patients, the most

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commonly associated injury was the LCL in 65.8%, (52/79), lateral retinaculum in 46.8% (37/79), as well as posteromedial corner (PMC) injuries in 38.0% (30/79), and lateral meniscus injuries in 34.18%. (**Table 3**)

Table 2. Female vs male comparison of all PCL and associated injury characteristics *(* indicates statistical significance; PCL, posterior cruciate ligament; ACL, anterior cruciate ligament; MCL, medial collateral ligament; LCL, lateral collateral ligament; PLC, posterolateral corner; PMC, posteromedial corner)*

Characteristic		*Total N*	*%*	*Females n=21*	*%*	*Males n=58*	*%*	*p-value*
Age				40.9± 19.5		35.2± 15.5		0.183
PCL tear grade	1	17	21.5%	4	(19.1%)	13	(22.4%)	0.748
	2	21	26.6%	5	(23.8%)	16	(27.6%)	0.737
	3	41	51.9%	12	(57.1%)	29	(50%)	0.575
PCL tear location	Proximal	32	40.5%	10	(47.6%)	22	(37.9%)	0.438
	Medial	29	36.7%	6	(28.6%)	23	(39.7%)	0.367
	Distal	18	22.8%	5	(23.8%)	13	(22.4%)	0.896
Associated Injury								
ACL	Partial	12	15.2%	7	**(33.3%)**	5	(8.6%)	0.007*
	Complete	3	3.8%	3	**(14.3%)**	0	(0%)	0.003*
	Any injuries	15	19%	10	**(47.62%)**	5	(8.62%)	<0.001*
MCL	Partial	9	11.4%	5	**(23.8%)**	4	(6.9%)	0.037*
	Complete	2	2.5%	1	(4.8%)	1	(1.7%)	0.448
	Any injuries	11	13.9%	6	**(28.57%)**	5	(8.62%)	0.024*
LCL	Partial	29	36.7%	10	(47.6%)	19	(32.8%)	0.226
	Complete	23	29.1%	6	(28.6%)	17	(29.3%)	0.949
	Any injuries	52	65.8%	16	(76.19%)	36	(62.07%)	0.242
Medial meniscus	Partial	12	15.2%	6	**(28.6%)**	6	(10.3%)	0.046*
	Complete	1	1.3%	0	(0%)	1	(1.7%)	0.545
	Any injuries	13	16.5%	6	(28.57%)	7	(12.07%)	0.081
Lateral meniscus	Partial	17	21.5%	4	(19.1%)	13	(22.4%)	0.748
	Complete	10	12.7%	8	**(38.1%)**	2	(3.5%)	<0.001*
	Any injuries	27	34.2%	12	**(57.14%)**	15	(25.86%)	0.01*
Medial gastrocnemius	Partial	11	13.9%	2	(9.5%)	9	(15.5%)	0.497
	Complete	13	16.5%	1	(4.8%)	12	(20.7%)	0.092
	Any injuries	24	30.4%	3	(14.29%)	21	(36.21%)	0.061
Lateral gastrocnemius	Partial	12	15.2%	0	(0%)	12	**(20.7%)**	0.024*
	Complete	7	8.9%	1	(4.8%)	6	(10.3%)	0.440
	Any injuries	19	24.1%	1	(4.76%)	18	**(31.03%)**	0.016*
Medial retinaculum	Partial	6	7.6%	6	(28.6%)	0	(0%)	<0.001*
	Complete	0	0.0%	0	(0%)	0	(0%)	-
	Any injuries	6	7.6%	6	**(28.57%)**	0	(0.00%)	<0.001*
Lateral retinaculum	Partial	15	19.0%	2	(9.5%)	13	(22.4%)	0.092
	Complete	22	27.8%	9	**(42.9%)**	13	(22.4%)	0.024*
	Any injuries	37	46.8%	11	(52.38%)	26	(44.83%)	0.552
Posterolateral Corner		23	29.1%	4	(19.1%)	19	(32.8%)	0.236
Posteromedial Corner		30	38.0%	15	**(71.4%)**	15	(25.9%)	<0.001*
Subchondral Fractures	Partial	18	22.8%	5	(23.81%)	13	(22.41%)	0.896
	Complete	19	24%	6	(28.57%)	13	(22.41%)	0.572
	All	37	46.8%	11	(52.38%)	26	(44.83%)	0.552
Bony Edema		30	37.9%	10	(47.62%)	20	(34.48%)	0.288

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Table 3. Most commonly associated structural injuries with PCL tears

	# of Patients	*%*
Lateral collateral ligament	52	(65.8%)
Lateral retinaculum	37	(46.8%)
Posteromedial corner	30	(37.9%)
Lateral meniscus	27	(34.2%)
Medial gastrocnemius	24	(30.3%)
Posterolateral corner	23	(29.1%)
Lateral gastrocnemius	19	(24.1%)
Anterior cruciate ligament	16	(20.3%)
Medial meniscus	13	(16.5%)
Medial collateral ligament	11	(13.9%)
Medial retinaculum	8	(10.1%)

When including all grades of PCL injuries, female patients with PCL injuries were found to more frequently sustain additional partial and complete ACL injury (33.3% vs. 8.6%, p=0.007) and (14.3% vs. 0%, p=0.003) respectively, complete lateral meniscus tear (38.1% vs. 3.5%, p<0.001), complete lateral retinaculum tear (42.9% vs. 22.4%, p=0.024), PMC (71.4% vs. 25.9%, p<0.001), partial medial meniscus tear (28.6% vs. 10.3%, p=0.046), partial MCL injury (23.8% vs. 6.9%, p=0.037), and partial medial retinaculum (28.6% vs. 0%, p<0.001). Patients in the male cohort on the other hand had more frequent partial lateral gastrocnemius injury (0% vs. 20.7%, p=0.024) (**Table 2**).

When comparing a subgroup of patients with complete (Grade 3) PCL tears, this type of injury was found to occur in women at a greater age compared to males (46.0±22.1 vs. 32.3±13.5, p=0.019).

In patients with Grade 3 PCL injuries, we also observed a significantly greater number of additional partial and complete ACL (33.3% vs. 6.9%, p=0.029, and 16.7% vs. 0%, p=0.024 respectively), complete lateral meniscus injury (25% vs. 3.5%, p=0.034), complete lateral retinaculum (41.7% vs. 17.2%, p=0.043), PMC (75% vs. 27.6%, p=0.005), and partial medial retinaculum (33.3% vs. 0%, p=0.001) in female patients. Male patients more frequently had PLC injuries (0% vs. 31%, p=0.029) and partial lateral gastrocnemius injury (0% vs. 27.6%, p=0.043) (**Table 4**).

Linear regression analysis between age and each type of additional injury in patients with Grade 3 PCL tears revealed significant findings only in female patients with a significant positive correlation between age and PCL tear location (R^2 = 0.5937, R = 0.77, p=0.003), with increasing age being associated with more distal tears (**Figure 2a**). We also observed significant negative correlations between age and additional ACL (R^2 = 0.3623, R = 0.6, =0.038), and lateral retinaculum (R^2 = 0.3325, R = 0.58, p=0.049) injuries (**Figure 2b, 2c**).

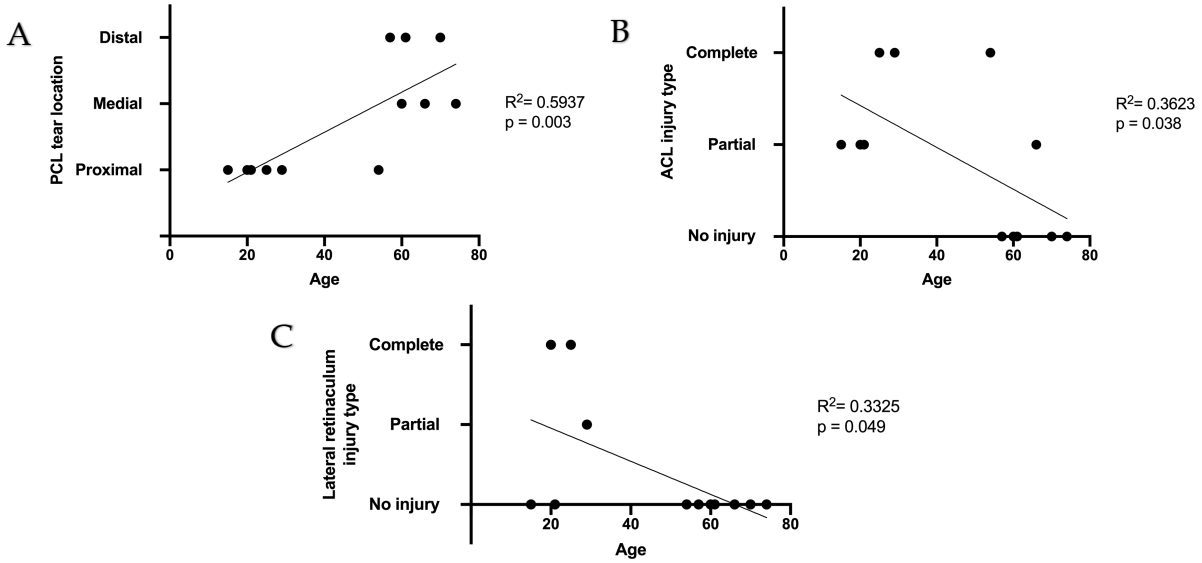

Figure 2. Linear regression analysis results are shown. 1a) PCL tear location vs age in female patients with complete PCL tears; 1b) Dependence of ACL injuries on age in female patients with complete PCL tears; 1c) Dependence of lateral retinaculum injuries on age in female patients with complete PCL tears

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Table 4. Female vs male comparison of Grade 3 PCL tears and associated injury characteristics *(* indicates statistical significance; PCL, posterior cruciate ligament; ACL, anterior cruciate ligament; MCL, medial collateral ligament; LCL, lateral collateral ligament; PLC, posterolateral corner; PMC, posteromedial corner)*

Characteristic		*Total N*	*%*	*Females n=12*	*%*	*Males n=29*	*%*	*p-value*
Age				46±22.1		32.3±13.5		0.019*
PCL tear location	Proximal	17	41.5%	6	(50%)	11	(37.9%)	0.475
	Medial	16	39.0%	3	(25%)	13	(44.8%)	0.236
	Distal	8	19.5%	3	(25%)	5	(17.2%)	0.568
ACL	Partial	6	14.6%	4	**(33.3%)**	2	(6.9%)	0.029*
	Complete	2	4.9%	2	**(16.7%)**	0	(0%)	0.024*
	Any injuries	8	19.5%	6	**(50.00%)**	2	(6.90%)	0.002*
MCL	Partial	8	19.5%	4	(33.3%)	4	(13.8%)	0.151
	Complete	2	4.9%	1	(8.3%)	1	(3.5%)	0.509
	Any injuries	10	24.4%	5	(41.67%)	5	(17.24%)	0.098
LCL	Partial	17	41.5%	6	(50%)	11	(37.9%)	0.475
	Complete	8	19.5%	3	(25%)	5	(17.2%)	0.568
	Any injuries	25	61%	9	(75.00%)	16	(55.17%)	0.236
Medial meniscus	Partial	7	17.1%	4	(33.3%)	3	(10.3%)	0.075
	Complete	0	0.0%	0	(0%)	0	(0%)	-
	Any injuries	7	17.1%	4	(33.33%)	3	(10.34%)	0.075
Lateral meniscus	Partial	11	26.8%	4	(33.3%)	7	(24.1%)	0.545
	Complete	4	9.8%	3	**(25%)**	1	(3.5%)	0.034*
	Any injuries	15	36.6%	7	(58.33%)	8	(27.59%)	0.063
Medial gastrocnemius	Partial	4	9.8%	0	(0%)	4	(13.8%)	0.176
	Complete	7	17.1%	1	(8.3%)	6	(20.7%)	0.339
	Any injuries	11	26.8%	1	(8.33%)	10	(34.48%)	0.086
Lateral gastrocnemius	Partial	8	19.5%	0	(0%)	8	**(27.6%)**	0.043*
	Complete	2	4.9%	0	(0%)	2	(6.9%)	0.351
	Any injuries	10	24.4%	0	(0.00%)	10	**(34.48%)**	0.019*
Medial retinaculum	Partial	4	9.8%	4	**(33.3%)**	0	(0%)	<0.001*
	Complete	0	0.0%	0	(0%)	0	(0%)	-
	Any injuries	4	9.8%	4	**(33.33%)**	0	(0.00%)	0.001*
Lateral retinaculum	Partial	7	17.1%	1	(8.3%)	6	(20.7%)	0.339
	Complete	10	24.4%	5	**(41.7%)**	5	(17.2%)	0.043*
	Any injuries	17	41.5%	6	(50.00%)	11	(37.93%)	0.475
PLC		9	22.0%	0	(0%)	9	**(31%)**	0.029*
PMC		17	41.5%	9	**(75%)**	8	(27.6%)	0.005*
Subchondral fractures	Partial	8	19.5%	2	(16.67%)	6	(20.69%)	0.767
	Complete	9	21.9%	4	(33.33%)	5	(17.24%)	0.257
	Any	17	41.5%	6	(50.00%)	11	(37.93%)	0.475
Bony edema		14	34.1%	7	**(58.33%)**	7	(24.14%)	0.036*

DISCUSSION

The main findings of this study were the following: female patients with PCL tears, when compared to their male counterparts, had greater rates of concurrent ligamentous and meniscal injuries and sustained complete PCL injuries at an older age. Furthermore, age-related variations in the distribution of PCL injury location and number of accompanying injuries were noted in females, but not males.

PCL injuries rarely exist in isolation and have been shown to typically present concurrently with other knee injuries, including ACL, MCL, or PLC injury.[2,6,17] In a study by Fanelli et al., only 6.5% (3/46) of PCL injuries isolated injuries, while 93.5% (43/46) of PCL injuries occurred in combination

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with other ligamentous injuries. Becker et al. reported that up to 79% (65/82) of multiligament knee injuries involved the PCL in a trauma setting.[18] In our study, we observed significant sex differences in the number of associated concurrent ligament injuries in patients with PCL injuries, with female patients more frequently having concurrent ACL and MCL injuries at a rate four to six times that of males.

The ACL is known to be one of the most frequently injured ligaments in the setting of PCL injury. Fanelli et al. reported that 21.2% of all PCL injuries were combined, as part of ACL/PCL/MCL injury.[2] Anderson et al. reported that the most commonly injured knee structures in acute PCL tears were posterolateral corner (58/79, 73%) and anterior cruciate ligament (ACL) (48/79, 61%).[19] Similarly, many other studies report a rate of 27–45% concomitant PCL and ACL injuries. [2,3,5,18,20] In our study, we additionally found that concomitant LCL 65.82% (52/79) and lateral retinaculum 46.84% (37/79) injuries were among the most common, however, we also noted that there were significant differences in the rate of injuries to these structures by sex.

In PCL injury patterns, it has been shown that concomitant MCL and PCL injuries can occur in 15-36% of cases.[7,19,21] While the rate of MCL injuries in male patients in our study was consistent and within this reported range, the prevalence of MCL injuries in female patients with PCL injuries was greater than previously reported and occurred at a rate four times that in males. Recognition of these patterns may help clinicians to identify the full extent of knee injuries in patients, and further studies are recommended to better identify the sex-specific risk factors that lead to these discrepancies.

The majority of PCL injuries have been reported to occur in 30 to 50-year-old patients with an average age of 33 years.[3,5] Although this was consistent with our study population, which had an average age at injury of 36 years, we found that the age at injury was significantly different between women and men (46 ± 22.1 in females vs. 32.3 ± 13.5 in males, p=0.019), with the average female patient being significantly older than the average male at the time of sustaining at PCL injury. In a cohort study by Sanders et al., similar results were reported with 53% of female patients being older than 40, whereas in the male group a majority (73%) of patients were younger than 40. Longo et al. reported the frequency of PCL reconstructive surgeries was strongly associated with age and sex, being more frequent among male patients aged 16–39 years old undergoing PCL reconstruction representing 64.9% of the total procedures.[4] The same was observed in two subsequent reports.[22,23] In addition, we observed a decrease in the number of concurrent PMC, ALC, and lateral retinaculum injuries with increased age in female patients who sustain a PCL injury, suggesting the nature of these injuries may be influenced by age, as well.

The results of this study should be interpreted in the context of some potential limitations. First, this was a retrospective study, with a limited sample size due to the uncommon nature of this injury. Second, this study was based on radiological assessments, and physical examination or surgical correlations of these findings were not confirmed. The specific location of edema and subchondral fractures were not specified in our study, which may have given greater insight into injury mechanisms. Finally, greater detail in clinical and demographic data could potentially be helpful in further understanding of sex-specific PCL injury patterns.

CONCLUSION

In our study, we found that PCL injury patterns varied between men and women, and that the prevalence of concurrent ligamentous and meniscal injury in women were more common than reported in the general literature. These findings suggest that further sex-specific studies are warranted on the differences in injury types and mechanism, as well as their clinical implications, to better understand and address knee ligament injuries in women.

Conflict of Interest Statement

The authors report no conflict of interest with the contents of this manuscript.

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