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Original Article

# Lower-limb asymmetry in healthy male athletes

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**Abstract.** [Purpose] This study aimed to determine lower extremity asymmetry in healthy males when participating in sports where non-contact injuries are common by comparing lower extremity muscle strength, jumping distance, and change of direction speed between the dominant and non-dominant legs. [Participants and Methods] Study participants included 16 healthy males who had been playing a specific sport for at least four years at the time of measurement. We measured the maximal isometric strength of five muscle groups and conducted six performance tests. The lower-limb symmetry index was calculated as follows: (non-dominant leg/dominant leg) × 100. [Results] Significant differences were found in the strength levels of hip flexors, hip abductors, knee flexors, and knee extensor muscles. The lower-limb symmetry index for all muscles, except for the hip flexors, ranged from 91% to 98%. In the performance tests, significant differences were found in the crossover hop test and the 90° change of direction test. The lower-limb symmetry index ranged from 96% to 103% in all the performance tests. [Conclusion] We suggest that leg dominance be considered in assessments for determining return to sports based on the type of tests employed.

**Key words:** Performance test, Lower-limb asymmetry, Dominant leg

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## INTRODUCTION

Anterior cruciate ligament (ACL) injuries are among the most common sports injuries, affecting more than 100,000 people per year in the United States[1)]. ACL injuries are classified into contact injuries, which are caused by external forces from contact with an opponent, and non-contact injuries, which do not involve contact with an opponent. ACL injuries in sports are often non-contact, especially those involving jump landing, cutting, and stopping motions[2)]. According to Kimura et al.[2)], basketball had the highest proportion of ACL reconstruction cases, followed by skiing, volleyball, soccer, judo, and badminton.

In clinical practice, performance tests are used to measure lower limb function as a simple index of return to sports after ACL reconstruction surgery. The performance tests involved measuring the jump distances in the forward, lateral, and vertical directions, as well as the speed of directional changes, on both the healthy and affected sides, followed by calculating the Lower-limb Symmetry Index, which represents the ratio between them. The recommended criteria for return to sports using lower-limb symmetry index are 85–90% or higher, with a recovery rate of 90% or more being particularly desirable[3, 4)].

Previous studies have reported that lower limb asymmetry is commonly observed in athletes. Šarabon et al.[5)] reported greater interlimb muscle asymmetry in soccer players than in basketball or tennis players, and Bishop et al.[6)] reported a left-right difference in jump height in the drop jump test in adult female soccer players. Other studies have reported an increased

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risk of sports-related injuries when lower extremity asymmetry exceeds 10%[7, 8]. The participants in studies examining lower-limb symmetry index in performance testing included healthy athletes and athletes who returned to sports after ACL reconstruction surgery. To determine the feasibility of returning to sports based on lower-limb symmetry index, it is necessary to understand the characteristics of the sport and identify the lower limb dominance of healthy athletes with no history of ACL injury.

The most common method of evaluating lower limb asymmetry is to compare the dominant and non-dominant legs. In some sports, a specific lower limb may be used more often, and the roles of the dominant and non-dominant legs may differ. Therefore, it is important to study lower limb asymmetry by comparing the dominant and non-dominant legs in athletes. However, few studies have compared asymmetry between the dominant and non-dominant legs, and further research is needed.

The purpose of this study was to determine lower extremity asymmetry in healthy males participating in sports where non-contact injuries are common by comparing lower extremity muscle strength, jumping distance, and change of direction speed between the dominant and non-dominant legs.

## PARTICIPANTS AND METHODS

Participant characteristics are shown in Table 1. The participants were 16 out of 24 healthy male participants who met the above criteria. The mean participant age (± standard deviation) was 21.6 ± 1.5 years, height was 174.1 ± 5.1 cm, and weight was 63.3 ± 9.1 kg. The participants were healthy males who had been playing a specific sport for at least four years at the time of measurement. The inclusion criteria were as follows: (1) healthy participants, (2) those who had been playing each sport for at least 4 years at the time of measurement, (3) those who were at least 18 years old at the time of consent, and (4) those who provided written consent to participate in this study. The exclusion criteria were (1) pain in the trunk or lower limbs, (2) injury within 3 months, (3) history of ACL injury or other orthopedic or neurological diseases, (4) chronic ankle instability, and (5) other conditions that made the participants unsuitable for inclusion in the study. The Japanese version of the Cumberland Ankle Instability Tool[9] was used as the selection criterion for chronic ankle instability, and participants with a score of 26 or higher were considered to have no chronic ankle instability and were recruited as participants. The leg on the side that kicks a ball was defined as the dominant leg, and the axis leg was defined as the non-dominant leg. Fourteen participants were right-footed and two were left-footed. This study was approved by the Kanazawa University Medical Ethics Review Committee (approval number: 111110). Participants were fully informed in writing and orally, and their consent was obtained.

Measurements were taken over two days, with the two days being no longer than one week apart. The participants were asked to refrain from excessive exercise on the day before and on the day of measurement, and the measurement was conducted under the least fatiguing conditions possible. Before the measurement, the participants performed an ergometer exercise for 5 min as a warm-up and then started the measurement, with three-minute rest in between.

Five muscle strength tests and six performance tests were performed.

Muscle strength was measured using a handheld dynamometer, μ-Tas F1 (ANIMA Corp., Tokyo, Japan), which assessed the maximum isometric strength of five muscle groups: the hip flexors, hip extensors, hip abductors, knee flexors, and knee extensors. For each muscle group, a 5-second isometric contraction was measured three times with three-minute rest between each measurement. The representative value of muscle strength was obtained by dividing the average of three trials by body weight.

**Table 1.** Participant characteristics, n=16

| Characteristic | Data |
|---|---|
| Participants (male) | 16 |
| Soccer | 6 |
| Basketball | 4 |
| Volleyball | 2 |
| Badminton | 4 |
| Age (years) | 21.6 ± 1.5 |
| Height (cm) | 174.1 ± 5.1 |
| Weight (kg) | 63.3 ± 9.1 |
| BMI (kg/m$^2$) | 20.8 ± 2.5 |
| Dominant (Right/Left) | 14/2 |
| Practice frequency (time/week) | 3.0 ± 1.7 |
| Practice time per session (hours) | 2.3 ± 0.4 |
| Years of experience (years) | 10.6 ± 3.1 |

Mean ± SD. BMI: body mass index.

Hip flexor strength[10] was measured in the sitting position, with the hip and knee joints flexed at 90°. The upper limbs were crossed in front of the chest and the pelvis and distal thigh were secured with belts. The sensors were positioned on the distal anterior thigh.

The measurement position for hip extensor strength[11] was set in the prone position with the back, pelvis, and distal thigh secured to the platform with belts. The sensor was positioned on the distal posterior thigh and no restrictions were placed on the upper limbs. Hip extensor strength was measured in the 0° mid-position of hip flexion and extension.

The hip abductor strength[12] was measured in the supine position with the chest, pelvis, and distal thigh secured to the platform with belts. The sensor was positioned on the distal lateral thigh and no restrictions were placed on the upper limbs. Hip abductor strength was measured at the 0° mid-position of hip adduction and abduction. During hip abduction, the participants were instructed to avoid compensatory hip flexion.

The knee flexor and extensor strength[13, 14] was measured in the sitting position with the hip and knee joints flexed at 90°. The upper limbs were crossed in front of the chest and the pelvis and distal thigh were secured with belts. To measure knee flexor strength, the fixation point was set posterior to the distal lower leg, and to measure knee extensor strength, it was set anterior to the distal lower leg. The height of the fixation points for the belt was adjusted to be parallel to the floor with a handheld dynamometer attached to the lower leg.

During hip flexion, knee flexion, and knee extension, the participants were instructed not to tilt their trunk forward or backward.

Six performance tests were used in this study (Fig. 1): the Single Leg Hop Test (single leg hop test), Cross Over Hop Test (cross over hop test), Side Hop Test (side hop test), Counter Movement Jump Test (counter movement jump test), 180° Change of Direction Test (180° change of direction test), and 90° Change of Direction Test (90° change of direction test).

In the single leg hop test[15], the participants jumped as far forward as possible from a single-leg standing position and landed on the same leg. Success was determined when the participant was able to maintain balance in the end position for three seconds.

In the cross over hop test[16], the participants performed three successive jumps as far forward as possible while crossing a 15 cm wide line on the floor to the left and right. The distance from the starting line to the heel at the third landing was measured. If the right leg was dominant, jumps with the dominant leg were defined as right-side outward and left-side inward. The starting position was set so that the participants first jumped inward, then outward, then inward. Success was determined when the participant was able to maintain balance in the final position for three seconds.

In the side hop test[17], the participant hopped as quickly as possible along a 30 cm wide line with one leg without restrictions on the upper limbs. As in the cross over hop test, if the dominant leg was right, the movement with the dominant leg was defined as right-side outward and left-side inward. If the dominant leg was left, the movement of the dominant leg was defined as left-side outward and right-side inward. The starting position was set so that the participants first jumped outward and then inward. The time taken for 14 roundtrips was measured, and the time taken for 10 roundtrips was calculated by excluding the first and last two roundtrips. If the total number of times the participant stepped on or could not cross the line was less than three, it was judged as “success”.

In the counter movement jump test[5, 18], the participants stood with their hands on the iliac crest and jumped upward from a single-leg standing position after sinking down, and the jumping height was measured. Jumping height was defined as the vertical distance between the midpoints connecting both posterior superior iliac spines from the stationary single-leg standing position to the highest point.

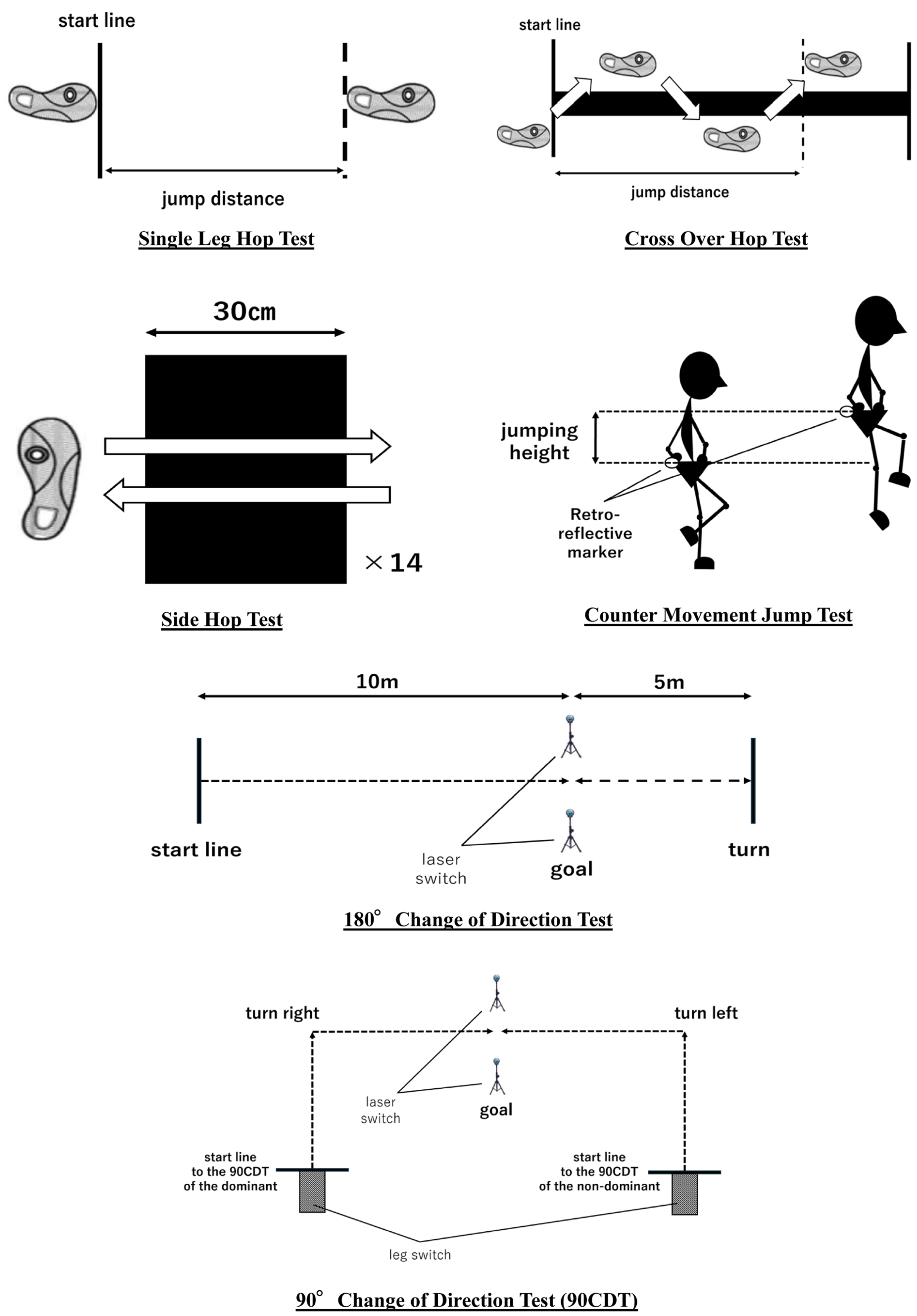
In 180° change of direction test[5, 19, 20], the participant sprints 15 m from the start line, performs a 180° turn at the turnaround line using either the dominant or non-dominant leg, and then sprints another 5 m at full speed. The laser switch was placed 10 m away from the starting line. The laser switch was set at the height of the participant’s anterior superior iliac spine, and the timer was set to activate when the participant passed through the laser switch and stop when the participant passed through it again. The time required to pass through the 2nd laser switch after passing through the 1st laser switch and turning back at the turnaround line was measured.

In 90° change of direction test[5, 20, 21], the participant sprints 5 m from the start line, makes a 90° turn at a cone placed 5 m ahead, and then sprints another 5 m at full speed. A leg switch was set at the starting line and a laser switch was set at the goal line. The laser switch was set to the height of the participant’s anterior superior iliac spine. The timer was set to start when the participant left the leg switch and stop when the participant passed through the laser switch. The “dominant leg 90° change of direction test” was defined as changing direction toward the dominant leg, while the “non-dominant leg 90° change of direction test” was defined as changing direction toward the non-dominant leg. In addition, the position of the dominant leg at the starting position was not restricted.

All the tests were performed alternately on the dominant and non-dominant legs. The order of performance tests and that of the dominant and non-dominant legs were random. Measurements were obtained after practice before each trial and were performed until three successful attempts were made for each leg.

A hand-held dynamometer (μ-tasF1, Anima, Tokyo, Japan) was used to measure muscle strength.

The performance test was conducted using a three-dimensional motion analyzer (VICON MX; Vicon Motion Systems, Oxford, UK). Retro-reflective markers, each 9.5 mm in diameter, were attached to the participant’s body. The markers were placed at three points: the left and right sides of the heels (the most posterior points at the same height as the second metatar-



The figure of 90° change of direction test shows the operation when the dominant leg is the right lower limb.

**Fig. 1.** Performance tests.

sal heads) and the midpoint between the posterior superior iliac spines. Additionally, for the single leg hop test and cross over hop test, markers were placed at the start line and the distance from the start line to the heels after the jump was measured. Marker tracking was performed using ten infrared cameras at a sampling frequency of 250 Hz. The jumping distances of single leg hop test and cross over hop test were calculated in the Y-axis direction using Nexus 2 (Vicon Motion Systems, Oxford, UK), based on the coordinates measured by the three-dimensional motion analyzer. The jumping distance of counter movement jump test was also calculated in the Z-axis direction based on the coordinates measured by the three-dimensional motion analyzer. Side hop test was measured using a force plate from the moment the ground reaction force disappeared on the third round trip to the time to the moment the ground reaction force occurred on the 12th round trip.

Muscle strength was represented as the average of three measurements divided by body weight, while the performance test was represented as the average of three measurements. The lower-limb symmetry index was calculated as (non-dominant leg/dominant leg) × 100.

The Modified R Commander 4.1.2 was used for the statistical analysis. Normality was tested using the Shapiro–Wilk test, and homogeneity of variance was tested using Levene's test for each muscle strength and performance test. For normally distributed data sets, a paired t-test was performed. For datasets that were not normally distributed, the Wilcoxon signed-rank test was performed. The significance level for statistical treatment was set at 5%.

## RESULTS

The muscle strength results are presented in Table 2. Significant differences were observed between the dominant and non-dominant legs in the hip flexor, hip abductor, and knee extensor muscles, all of which were significantly higher in the dominant leg. The lower-limb symmetry index was as low as 88% for the hip flexors, whereas the strengths of the other muscles ranged from 91% to 98%.

The results of the performance tests are listed in Table 3. Significant differences were observed in cross over hop test and 90° change of direction test when comparing the dominant and non-dominant legs. The dominant leg showed a longer jump distance in the cross over hop test, whereas the non-dominant leg had a shorter measurement time in the 90° change of direction test. The lower-limb symmetry index ranged from 96% to 103% for all the tests (Table 3).

## DISCUSSION

Significant differences in muscle strength were observed in the hip flexors, hip abductors, and knee extensors, all of which were greater in the dominant leg. The performance tests showed significant differences in the cross over hop test and 90° change of direction test, with the dominant leg having a longer jump distance in the cross over hop test and the non-dominant leg having a shorter measurement time in the 90° change of direction test.

Regarding muscle strength, there are reports indicating that quadriceps and hamstring asymmetry is approximately 5% in male basketball players and 8–9% in male soccer players[22], The results of the present study also showed asymmetry ranging from 3–9% except for hip flexors, which is similar to the previous study. However, there is a report that it is not uncommon for athletes to have asymmetry greater than 10%[23]. As a result, there was no consistent trend regarding acceptable levels of asymmetry. Increased asymmetry not only increases the risk of ACL injury but also the risk of various other injuries, leading to performance degradation[24]. Implementing interventions to address asymmetry during training may help reduce the risk of injury and improve performance.

**Table 2.** Comparison of dominant and non-dominant leg in maximal isometric muscle strength, n=16

| | Dominant (kgf [kgf/kg]) | Non-dominant (kgf [kgf/kg]) | | Lower-limb Symmetry Index (%) |
|---|---|---|---|---|
| Hip flexion | 29.1 ± 4.5 [0.5 ± 0.1] | 25.9 ± 5.4 [0.4 ± 0.1] | * | 88.1 ± 11.6 |
| Hip extension | 42.1 ± 6.7 [0.7 ± 0.2] | 40.0 ± 7.6 [0.6 ± 0.1] | | 94.7 ± 9.2 |
| Hip abduction | 21.1 ± 3.8 [0.3 ± 0.1] | 18.8 ± 3.2 [0.3 ± 0.1] | ** | 91.0 ± 16.6 |
| Knee flexion | 24.2 ± 3.2 [0.4 ± 0.1] | 23.7 ± 3.5 [0.4 ± 0.1] | | 98.0 ± 8.4 |
| Knee extension | 51.9 ± 8.3 [0.8 ± 0.1] | 48.7 ± 9.0 [0.8 ± 0.1] | ** | 94.0 ± 9.8 |

Mean ± SD (Measured value [Calculated value]).
*, **: Dominant vs. Non-dominant.
*$p<0.05$, **$p<0.01$.
Dominant (Right/Left: 14/2).

**Table 3.** Comparison of dominant and non-dominant leg measurements for each performance test, n=16

| | Dominant | Non-dominant | | Lower-limb Symmetry Index (%) |
|---|---|---|---|---|
| Single Leg Hop Test (cm) | 166.5 ± 17.5 | 162.4 ± 16.4 | | 97.7 ± 5.0 |
| Cross Over Hop Test (cm) | 462.3 ± 52.3 | 450.7 ± 54.5 | ** | 97.5 ± 4.1 |
| Side Hop Test (s) | 8.2 ± 1.0 | 8.2 ± 1.0 | | 100.8 ± 2.7 |
| Counter Movement Jump Test (cm) | 27.2 ± 3.6 | 27.8 ± 4.3 | | 102.1 ± 7.5 |
| 180° Change of Direction Test (s) | 2.5 ± 0.1 | 2.5 ± 0.1 | | 101.4 ± 2.5 |
| 90° Change of Direction Test (s) | 2.4 ± 0.1 | 2.3 ± 0.2 | * | 96.4 ± 4.2 |

Mean ± SD.
*, **: Dominant vs. Non-dominant.
*$p<0.05$, **$p<0.01$.
Dominant (Right/Left: 14/2).

Regarding performance tests, many previous studies on healthy athletes have shown an average lower-limb symmetry index of 90% or higher for the dominant and non-dominant legs[15, 16, 25, 26]. In addition, the lower-limb symmetry index for the dominant and non-dominant legs in individual performance tests is reported to be 95–99% for the single leg hop test[15, 27, 28], 98–99% for the cross over hop test[15, 16], and 100–103% for the side hop test[16, 28]. As for counter movement jump test, some reports indicate 95–98%[27, 29, 30] difference, but many studies suggest that there is no difference in jump distance between the dominant and non-dominant legs[31]. The lower-limb symmetry index for 180° change of direction test and 90° change of direction test is reported to be 102–103%[20, 21], and the measurement time for changing direction with the dominant leg is reported to be shorter. In any case, the asymmetry between the dominant and non-dominant legs was within 10% in all tests, indicating that the results of previous studies and those of the present study were almost equivalent.

The only tests that showed significant differences in the results of this study were the cross over hop test and 90° change of direction test, both of which were below 100%. This result indicated that the cross over hop test showed a greater jump distance for the dominant leg, whereas the 90° change of direction test showed a shorter measurement time for the change in direction to the non-dominant leg. In healthy participants, the jumping distance of the non-dominant leg was reported to be 2% shorter than the dominant leg[27]. Generally, the dominant leg performs movements that require functional and fine-tuning skills, whereas the non-dominant leg is used as the stabilizing axis to balance the body[32]. Miyaguchi et al.[33] reported that horizontal jumping requires more balancing ability and coordination throughout the body than vertical jumping and that individuals may potentially experience a participative sense of dominance with the dominant leg during continuous movement. In continuous jumps, such as cross over hop test, a stable landing motion is necessary first, because the takeoff and landing motions are repeated. It has been reported that knee extensor strength is involved in landing motion in hop test[34–36]. In addition, the psoas major muscle, which is the main muscle for hip flexion, originates from the lumbar spine and inserts into the lesser trochanter, contributing to the stabilization of the lower limbs and trunk, thereby improving balance[37–39]. For the hip abductor muscles, it is suggested that they play a role in generating substantial hip abduction torque during take-off and immediately after landing in single-leg jumps, contributing to the acquisition of vertical ground reaction force and maintaining the trunk in an upright position[40]. The single leg hop test and counter movement jump test are single-jump, one-shot jumping movements, whereas the cross over hop test involves continuous movements, which may increase the load on the lower limbs and make them more susceptible to the effects of muscle strength. The results of this study showed significant differences in the strengths of the hip flexor, hip abductor, and knee extensor muscles, which may have resulted in significant differences in jumping distance in the cross over hop test.

Regarding changes in direction in 90° change of direction test, the deceleration ability before a change of direction is important[41], and factors such as lower limb muscle strength, trunk orientation, and ground contact time are influential[42]. The hip and knee joints are important for deceleration, and a significant relationship between knee extensor muscle strength and deceleration ability has been reported[43]. In this study, a significant difference in knee extensor strength was observed, which may have affected deceleration and changes in directional abilities. However, because this study did not analyze movement during a change in direction, it is unclear which lower limb is predominantly used during changes in direction. Therefore, the results of this study alone are insufficient to make a statement, and further studies are required.

This study found a significant difference between the dominant and non-dominant legs in the cross over hop test and 90° change of direction test, even when both lower limbs were healthy. This suggests that the decision to return to sports should consider not only the lower-limb symmetry index between the healthy and affected limbs but also whether the affected limb is the dominant or non-dominant leg.

One limitation of this study is that it included only16 participants, which may have affected overall reliability. In this study, we included healthy males who participated in various sports. However, movement characteristics may differ depending on the sport. Therefore, the results of this study have limitations because different sports were grouped together for the analysis. In addition, different positions within the same sport might influence the frequency of dominant and non-dominant leg usage as well as the style of play. Therefore, the lack of analysis by position is considered one of the limitations of this study.

In a comparison of lower limb asymmetry between the dominant and non-dominant legs in healthy male athletes, significant differences were found in muscle strength and performance tests. In fact, when assessing return to sports for patients after ACL reconstruction, the dominant leg may need to be considered, depending on the tests used.

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## *Conflict of interest*

There are no conflicts of interest to disclose in connection with this study.

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