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Kneeling Leg Curl with Internal Rotation Training Improves Agility in Patients with Anterior-posterior Laxity of Knee

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Objective: Whether strengthening exercises emphasizing on internal rotators of the knee are more effective in improving shuttle-run agility of the knees with anterior-posterior laxity (AP laxity).

Methods: Twenty men with AP laxity of knee were randomly assigned to the three experimental groups in different strengthening modes: plate-loaded squat press (SP), plate-loaded kneeling leg curl with internal rotation (KLCIR), and kneeling leg curl (KLC). Control group with stable knees received no training. Anterior-posterior laxity, shuttle-run agility, and isokinetic strength were evaluated before and after training.

Results: Those with AP laxity of knee have poorer performance in the shuttle run test than their contralateral sound side, and this vulnerability is improved after six-week SP or KLCIR training. Isokinetic strength of medial hamstring is increased after KLCIR and SP training. The anterior displacement by KT 2000 are decreased among the three training groups.

Conclusions: KLCIR, as SP, emphasizing knee internal rotators, enhances both AP laxity and shuttle-run agility. KLCIR can be either an advanced or an alternative mode to SP in the strengthening exercise of knees with AP laxity. (Tw J Phys Med Rehabil 2013; 41(1): 21 - 30)

Key Words: anterior cruciate ligament, laxity, muscle strengthening, athletic performance

INTRODUCTION

It is well known that joint instability negatively impacts on functional performance. The patients with anterior-posterior laxity (AP laxity) of knee, anterior cruciate ligament (ACL) insufficiency for instance, have been reported to have slower shuttle run than the healthy population.[1] Knees with AP laxity are also prone to develop ACL injury.[2,3] Although ACL injuries may result from the knee collision,
70% of them are due to noncontact movements, including abrupt brakes or changing directions at high speed (i.e. side-step cuttings and crossover cuttings).\cite{4-6} In such condition, one must at first have his axial foot fixed on the ground to absorb the momentum oriented from the original direction. Insufficient eccentric strength of muscle or ligament is likely to trigger injuries of muscle and ligament.\cite{6,7}

Generally, it is agreed that the risk of ligament injuries can be reduced by strengthening a specific muscle group to compensate the dynamic and static stability.\cite{8} Traditionally, the strengthening exercise of ACL insufficiency has been an emphasis on the hamstring and quadriceps with an attempt to decrease the AP laxity as well as the shearing force of ACL.\cite{9-11} Nonetheless, from the aforementioned pathomechanism of ACL injuries, the knee rotators should be valued as what they are supposed to be.\cite{12,13} The internal rotators of the knee joint (semitendinosus, semimembranosus and gracilis) are highly related to ACL injuries.\cite{7} However, the strength of the knee rotators is often neglected and even sacrificed as an autograft for the ACL reconstruction.\cite{14,15}

Progressive resistance exercise can be modified to strengthen internal rotators of the knee. We aimed to find out whether AP laxity had a negative impact on the to-and-fro running agility. In addition, the strengthening effect of thigh muscle that is more specific to internal rotators on AP laxity and agility would be explored.

### METHOD

#### Design

This is a randomized controlled clinical trial registered in ClinicalTrials.gov (identifier: NCT01170546). Twenty participants in the experimental group were randomly assigned into three groups by drawing a lot in a concealed envelope: plate-loaded squat press (SP) (n=7), plate-loaded kneeling leg curl with internal rotation (KLCIR) (n=7) and kneeling leg curl (KLC) (n=6). No participant dropped out during the study. Eight control participants neither received any training nor was engaged in body-building on their own during the training period. Every participant was asked to fill in basic information, including age, body height, and body weight. Before and after resistance training, KT-2000, agility, and isokinetic strength were assessed (Figure 1).
**Participants**

Knee joint laxity was surveyed by a KT-2000 test (MED Metric Co., San Diego, USA) in our department. The AP laxity of the knee joint in this study was defined as anterior displacement over 3 mm discrepancy between bilateral knees by a KT-2000 test. One hundred and seventy-three students were tested and 30 met the criterion, including 22 males and 8 females. Two males were excluded due to medical histories of lower limbs fracture and arthritis. Besides, eight female students were eliminated to avoid gender difference. Another 8 male students with stable knees without any medical history of knee injuries were included in the control group. Stable knees were defined as a discrepancy less than 1.5mm between bilateral knees by a KT-2000 test.\[16,17\] The participants in both experimental and control groups lived a sedentary lifestyle.

**Intervention**

Three training modes were chosen. (I) SP, or called angled leg presses (Figure 2A): the participant was instructed to position his back properly against the backrest on a machine, with the feet slightly apart. He was instructed to place his feet higher on the foot plate and draw his two knees as close as possible while the knees flexed so that medial hamstring would bear more tension in the course of knee flexion.\[18\] This is a closed-kinetic chain (CKC) exercise and is expected to strengthen the quadriceps and hamstring with emphasis on the medial hamstring. (II) KLCIR (Figure 2B): the participant was instructed to point toes toward medial side as knee flexing. This is an open-kinetic chain (OKC) exercise and medial hamstring is emphasized.\[19\] (III) KLC, an OKC exercise, is intended to strengthen the hamstring muscle without lateralization emphasized. The training phase had been lasting for 6 weeks. Each participant had to accomplish three training workouts weekly under supervision by licensed athletic trainers. A workout contained five sets for each lower limb, which were composed of 20 (repetitions)×60% (one repetition maximum \[1-RM\]) for warm up, 15×65% , 12×70% , 8×75% and 20×60% with a two-minute resting interval between each set. Pretest 1 RM weight values were determined for all subjects using a standardized 1 RM protocol.\[20\] During the six-week rehabilitation course, they were not allowed to be involved in any other regular fitness activities or sports.

**Outcome measures**

**Anterior-posterior laxity**

The KT-2000 knee ligament arthrometer (MED Metric Co., San Diego, USA) is designed to assess the AP laxity of the knee joint. The discrepancy of anterior displacement between the sound side and the lesion side had been reported and applied in evaluating the static stability of the knee, and is also used as one of the references for the ACL reconstruction surgery.\[16,17\] In this current study, a discrepancy less than 1.5mm was normally accepted when 20-pound anterior traction force was exerted on the tibia with the knee joint in 20° flexion. In contrast, ACL laxity was defined as a discrepancy over 3mm, which was highly related to ACL injury.\[16,17\]
Agility

Agility was measured by a 6-meter left-and-right shuttle run (Figure 3). A good dynamic stability of the knee is necessary for changing the movement direction.\(^{[8,21]}\) Each participant started running from the midline to the left terminal and then stepped on the square with his left foot. Then, the participant used the left leg as the axis and turned around to the right side. The participant then ran to the right terminal. Once the front foot was crossing the midline, this was the first round for testing the agility of left knee. The participant kept running to the right terminal without stopping on the midline, stepping on the square with his right foot, turning around to the left side, and running toward the left terminal. This was the first round of right knee test as the participant’s front foot crossed the midline. Whenever the front foot crossed the midline, a timer was clocked. The time interval in seconds between the 1\(^{\text{st}}\) and the 2\(^{\text{nd}}\) time clocked was the 1\(^{\text{st}}\) measure of the left knee agility, and the time interval between the 2\(^{\text{nd}}\) and the 3\(^{\text{rd}}\) was the 1\(^{\text{st}}\) measure of the right knee agility, and so forth. There were five-round tests for the agility of right and left knees respectively. Three raters were assigned respectively at the midline, right and left terminals. The square at the right or left terminal ends was 10 inches wide and 3 meters away from the midline. It would be recognized as a qualified round if the plantar surface of the foot ever contacted any part of the square; otherwise, the participant would be asked to repeat the whole set consisting of five rounds. Three sets were collected and averaged. The rest interval between each set should be long enough for the examinee to feel relaxed before the next set. The participant was asked to run as fast as possible. The average time difference of 3 sets between the affected and the sound side was regarded as the agility of the affected side. The greater the difference was, the poorer the agility would be. A practice session was given prior to the actual beginning of the study to avoid learning effect.

Prior to the study, intrarater test-retest reliability was established. Nine participants, including four in the experimental groups and five in the control group, took the agility exam twice in separated days. The intraclass correlation coefficient was 0.78.

Isokinetic strength

Cybex NORM (Cybex International, Inc, Ronkonkoma, New York, U.S.A.) was employed to evaluate isokinetic muscle strength before and after training. Tests were conducted in two different motion modes which included the flexor/extensor and the internal/external rotator. In the former, the range of motion was set in the range of 0-90\(^\circ\). Maximal concentric force had been performed for five times at the angular velocity of 60\(^\circ\), 120\(^\circ\) and 180\(^\circ\) per second, respectively. Peak torque was taken to represent muscle strength.\(^{[22]}\) Only smooth and similar curves with a peak torque which was no less than 90\% of the maximum would be taken.\(^{[19,23]}\) The assessment of isokinetic strength of internal/external rotator was generally similar to flexor/extensor. The ankle joint was fixed into 30\(^\circ\) dorsiflexion with an air-stirrup ankle brace (Aircast, Summit, NJ) to limit unnecessary inversion/eversion movement, which might affect measurement of knee joint rotation.\(^{[15]}\) In addition, the knee and hip joints were kept in 90\(^\circ\), and the range of motion of knee rotation was set in the range between 25\(^\circ\) internally and 35\(^\circ\) externally.

Data analysis

Data are expressed as mean ± standard error of mean (SEM). SPSS version 18.0 Windows was used for statistic analysis. Nonparametric analysis, including Kruskal-Wallis Test, Wilcoxon Test and Mann-Whitney test, was applied. Significance was defined as P<0.05. Intrarater reliability was assessed with intraclass correlation coefficient.

RESULTS
Demographic Characteristics (Table 1)

Age, body height, and body weight revealed no significant differences among the four groups.

Anterior-posterior laxity (Table 2)

The mean discrepancy between bilateral knees in all the three experimental groups before training exercise was greater than 3mm, compared to 1.11mm in the control group. Significant within-group improvements in all three experimental groups were noted after exercise training. Moreover, overall between-group comparisons were significantly different in pre-training status, but not in post-training status. This indicated that hamstring strengthening exercises in all the three modes could reduce the mean discrepancy between bilateral knees to the comparable extent and thereby improve AP laxity.

Agility (Table 3)

In the pre-training, the differences of agility discrepancy were significant between KLCIR vs. control groups and between KLC vs. control groups, although only borderline between SP vs. control groups (P=0.061). All the three experimental groups had greater bilateral agility discrepancy than the control group, which suggested that the knee with AP laxity also had poorer agility than that of its sound side. The within-group analysis revealed that agility was improved significantly in SP and KLCIR groups, but not in the KLC and control groups. Between-group analysis also showed no significant difference after training between SP vs. control and between KLCIR vs. control. However, significant difference remained between KLC vs. control groups. This support further the training effect on agility occurred only in SP and KLCIR groups.

Isokinetic Strength (Table 4)

The SP group showed significant improvement in extensor and flexor strength at the angular velocity of 180° per second and flexor at 60° per second. In the KLCIR group, the strength of hamstring was significantly gained under three different angular velocities. In addition, the strength of internal rotators was significantly improved at the angular velocity of 60° per second. In the KLC group, only the strength of knee flexors was significantly gained.

### Table 1. Demographic characteristics

<table>
<thead>
<tr>
<th></th>
<th>SP (n=7)</th>
<th>KLCIR (n=7)</th>
<th>KLC (n=6)</th>
<th>Control (n=8)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>20.3±0.49</td>
<td>20.6±0.42</td>
<td>20.3±0.8</td>
<td>21.5±0.78</td>
<td>0.604</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>176.8±2.44</td>
<td>170.8±1.33</td>
<td>173.7±2.29</td>
<td>177.4±2.58</td>
<td>0.147</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>74.2±3.17</td>
<td>63.8±2.81</td>
<td>70.5±3.48</td>
<td>69.3±2.91</td>
<td>0.215</td>
</tr>
</tbody>
</table>

SP: plate-loaded squat press, KLCIR: plate-loaded kneeling leg curl with internal rotation, KLC: plate-loaded kneeling leg curl Kruskal-Wallis test, among 4 groups; Values are mean ± SEM.

### Table 2. Static stability

<table>
<thead>
<tr>
<th>affected - sound side (mm)</th>
<th>SP (n=7)</th>
<th>KLCIR (n=7)</th>
<th>KLC (n=6)</th>
<th>Control (n=8)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pretraining</td>
<td>3.27±0.34</td>
<td>3.90±0.54</td>
<td>3.27±0.34</td>
<td>1.11±0.27</td>
<td>0.004* (KW)</td>
</tr>
<tr>
<td>posttraining</td>
<td>1.77±0.33</td>
<td>1.65±0.22</td>
<td>2.00±0.18</td>
<td>1.26±0.15</td>
<td>0.115 (KW)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.028* (W)</td>
<td>0.028* (W)</td>
<td>0.043* (W)</td>
<td>0.731 (W)</td>
<td></td>
</tr>
</tbody>
</table>

KW: Kruskal-Wallis test, among 4 groups; W: Wilcoxon test, within group, pre vs post; *p<.05; Values are mean ± SEM.
Table 3. Agility (shuttle-run test)

<table>
<thead>
<tr>
<th></th>
<th>SP (n=7)</th>
<th>KLCIR (n=7)</th>
<th>KLC (n=6)</th>
<th>Control (n=8)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretraining</td>
<td>0.30±0.06</td>
<td>0.42±0.10</td>
<td>0.49±0.06</td>
<td>0.10±0.06</td>
<td>0.007*  (KW)</td>
</tr>
<tr>
<td>p-value (experimental vs. control)</td>
<td>0.061 (MW)</td>
<td>0.028* (MW)</td>
<td>0.002* (MW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posttraining</td>
<td>0.08±0.04</td>
<td>0.01±0.1</td>
<td>0.44±0.09</td>
<td>0.03±0.11</td>
<td>0.039*  (KW)</td>
</tr>
<tr>
<td>p-value (experimental vs. control)</td>
<td>0.897 (MW)</td>
<td>0.796 (MW)</td>
<td>0.033* (MW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p-value (pretraining vs. posttraining)</td>
<td>0.028* (W)</td>
<td>0.028* (W)</td>
<td>0.753 (W)</td>
<td>0.401 (W)</td>
<td></td>
</tr>
</tbody>
</table>

W: Wilcoxon test, within group, pre vs post; MW: Mann-Whitney test, between group, SP/KLCIR/KLC vs Control; KW: Kruskal-Wallis test, among 4 groups; *p<.05; Values are mean ± SEM.

Table 4. Concentric peak torque of the affected knee (Newton-meter)

<table>
<thead>
<tr>
<th></th>
<th>SP (n=7)</th>
<th>KLCIR (n=7)</th>
<th>KLC (n=6)</th>
<th>Control (n=8)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular velocity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pre 60°/sec 60°/sec 120°/sec 180°/sec 60°/sec 120°/sec 180°/sec 60°/sec 120°/sec 180°/sec</td>
<td>381.17±27.65</td>
<td>296.17±27.42</td>
<td>234.17±17.15</td>
<td>188.67±15.38</td>
<td>311.33±46.97</td>
</tr>
<tr>
<td>post 60°/sec 60°/sec 120°/sec 180°/sec 60°/sec 120°/sec 180°/sec 60°/sec 120°/sec 180°/sec</td>
<td>408.50±16.22</td>
<td>313.00±18.24</td>
<td>255.50±18.57</td>
<td>290.67±27.60</td>
<td>245.50±14.65</td>
</tr>
<tr>
<td>p-value</td>
<td>0.046* 0.058 0.028** 0.046* 0.046* 0.046* 0.028* 0.028* 0.027* 0.078 0.08 0.158</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DISCUSSION

The experimental findings revealed that the knee with AP laxity showed poorer agility than the sound side; this vulnerability could be improved significantly only in the SP and KLCIR training modes, not in the KLC mode. In addition, the internal rotator (medial hamstring) strength was also increased in the SP and KLCIR training modes, although significance was only found in the latter. Internal rotator strengthening to some extent seemed to be essential for agility performance.

In comparison with the isokinetic muscle strength of OKC exercise training between the KLCIR and KLC groups, knee flexors were significantly strengthened in both while the internal rotators only in the former. Meanwhile, the agility was also significantly improved in the KLCIR group, but not in the KLC group. As a result, the improvements of agility in the KLCIR group could be specifically related to the increased strength of knee internal rotators. Additionally, the 6-meter-shuttle run can be a reliable functional test to assess agility performance in the population with anterior drawer laxity.

The tibia rotation relative to the femur is a basic biomechanic motion in the transverse plane of knee, affecting gait and some other motion abilities. Its largest range of motion is 30° internally and 45° externally as knee in 90° flexion, and 0° as knee in full extension because of anatomic limitation. As walking or running, ankle movements drive tibia rotation and subsequently contribute to the rotation of tibiofemoral joint. This phenomenon is exaggerated in direction-changing motion. As a result, much greater torsion is exerted on the knee joint. If the strength of knee stabilizers is unable to counteract the torsion, agility could be under-performed and furthermore, related ligaments or muscles could be...
Internal rotators of tibia cooperate with ACL to provide strength for balancing external rotation momentum caused by body inertia. The strength of internal rotators, namely semitendinosus, semimembranosus and gracilis, is highly correlated to knee stability and ACL injuries. Thus, the strengthening exercises of knee internal rotators should be emphasized in addition to hamstrings and quadriceps.

In the current investigation, the AP laxity was defined as anterior displacement over 3 mm bilateral discrepancy by a KT-2000 test. Previous studies demonstrated that in those who have met this criteria, 85% of them have complete ACL tears and the other 15% have partial tears. In the surgery of ACL reconstruction, semitendinosus and/or gracilis tendons are often harvested as ACL autograft. Nevertheless, some studies suggested that loss of these two tendons should reduce the muscle strength of knee internal rotators and thereby deteriorate stability. Moreover, the decreased muscle strength of knee internal rotators was reported in relation to less-perfect performance in some sports, such as skiing. The trade-off between static stabilizer (ACL) and dynamic stabilizer (medial hamstring muscle) should be weighted before surgery or compensated through strengthening after surgery. Strengthening exercises can be divided into CKC and OKC, and the former had been emphasized more in ACL rehabilitation. The CKC exercise is accentuated on the cocontraction of agonist and antagonist while the OKC exercise is on agonist contraction. This is compatible with our result and indicating that both quadriceps and hamstrings were strengthened significantly in the SP mode. When the knee joint is gradually extending in SP, the quadriceps contraction activity will be increasing while the hamstring activity is decreasing, and vice versa. In this process, tibia anterior displacement caused by the contraction of quadriceps is partially offset by the cocontraction of hamstring muscles; therefore, the shearing force of ACL is reduced. Besides, the tibiofemoral compressive force, which is created more by the CKC exercise than by the OKC one, is also believed to limit the anterior displacement of tibia in relation to femur.

Leg curl, an OKC exercise, is an effective and popular training mode to strengthen hamstring muscle, which is shown in the results of this current study (Table 4). Furthermore, if the tibia is internally rotating in the process of flexion (KLCIR), the training effect may be stressed more on internal rotators as shown in part of our results (Table 4). Conversely, if one is externally rotating the knee during the course of flexion, biceps femoris is about to be more emphasized. In this current study, SP and KLCIR made significant improvements in both stability and agility. Therefore, KLCIR can be an advanced mode to SP in the strengthening exercise of ACL rehabilitation. As weight bearing is inappropriate in some conditions such as meniscus tear and can decrease healing potential, KLCIR (an OKC exercise) can be an alternative mode to SP.

In addition, the findings of AP laxity and isokinetic strength revealed that three modes of exercises were all beneficial for improving AP laxity and hamstring (flexor) strength. Hamstring and ACL cooperate to restrain the anterior displacement of tibia in relation to femur when quadriceps femoris muscle contracts. Accordingly, the hamstring muscle strength may compensate ACL insufficiency and also reduces the risk of further injuries to some extent.

The shortcomings of the study are the small sample size and the participants who were not true ACL-injured patients. Further investigation is needed for its clinical application.

CONCLUSION

This study revealed that the knee with anterior drawer laxity can be compensated by hamstring strengthening exercise in all three training modes. We also found that the knee with AP laxity features poorer agility than that of its sound side, and such vulnerability is very likely to be amended in either SP or KLCIR training mode. Both KLCIR and SP, emphasizing knee internal rotators, reveal significant improvements in both AP laxity and to-and-fro running agility, but KLCIR is more effective in internal rotator strengthening. As far as resistance training in the patients with AP laxity of knee, KLCIR can be either an advanced or alternative mode to SP.

REFERENCES


以內旋跪姿腿後勾舉強化膝內轉肌群改善膝前後鬆弛病人之敏捷度

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台北市立體育學院 體育與健康學系² 運動科學研究所³
周適偉診所⁴

目的: 探討加強膝關節內轉肌群的肌力訓練是否可有效改善膝前後鬆弛病人之敏捷度。

方法: 20位有膝關節前後鬆弛的男性被隨機分配到三個實驗組，執行不同模式的肌力訓練: 斜躺腿部推蹬訓練、內旋跪姿腿後勾舉訓練及一般跪姿腿後勾舉訓練。膝關節穩定的對照組則不進行訓練。評估則為訓練前後膝關節前後穩定度、折返跑敏捷度和等速肌力。

結果: 和自己的正常腳相比，前後鬆弛的膝關節該側折返跑敏捷度較差，此可經由六個星期的斜躺腿部推蹬或內旋跪姿腿後勾舉訓練改善。斜躺腿部推蹬或內旋跪姿腿後勾舉可強化內轉肌之等速肌力。三種訓練模式皆能減少 KT2000 測試中前後位移的程度。


關鍵詞: 前十字韌帶(anterior cruciate ligament)，鬆弛(laxity)，肌力訓練(muscle strengthening)，運動表現(athletic performance)