[Athletic Training]

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Sagittal Plane Knee Biomechanics and Vertical Ground Reaction Forces Are Modified Following ACL Injury Prevention Programs: A Systematic Review

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Context: Injuries to the anterior cruciate ligament (ACL) occur because of excessive loading on the knee. ACL injury prevention programs can influence sagittal plane ACL loading factors and vertical ground reaction force (VGRF).

Objective: To determine the influence of ACL injury prevention programs on sagittal plane knee biomechanics (anterior tibial shear force, knee flexion angle/moments) and VGRF.

Data Sources: The PubMed database was searched for studies published between January 1988 and June 2008. Reference lists of selected articles were also reviewed.

Study Selection: Studies were included that evaluated healthy participants for knee flexion angle, sagittal plane knee kinetics, or VGRF after performing a multisession training program. Two individuals reviewed all articles and determined which articles met the selection criteria. Approximately 4% of the articles fulfilled the selection criteria.

Data Extraction: Data were extracted regarding each program's duration, frequency, exercise type, population, supervision, and testing procedures. Means and variability measures were recorded to calculate effect sizes. One reviewer extracted all data and assessed study quality using PEDro (Physiotherapy Evidence Database). A second reviewer (blinded) verified all information.

Results: There is moderate evidence to indicate that knee flexion angle, external knee flexion moment, and VGRF can be successfully modified by an ACL injury prevention program. Programs utilizing multiple exercises (ie, integrated training) appear to produce the most improvement, in comparison to that of single-exercise programs. Knee flexion angle was improved following integrated training (combined balance and strength exercises or combined plyometric and strength exercises). Similarly, external knee flexion moment was improved following integrated training consisting of balance, plyometric, and strength exercises. VGRF was improved when incorporating supervision with instruction and feedback on proper technique.

Conclusion: ACL injury prevention programs that are aimed at modifying sagittal plane knee biomechanics and VGRF should use an integrated training approach that incorporates instruction and feedback on proper movement technique.

Keywords: anterior cruciate ligament; ACL; prevention; training; exercise; knee flexion; vertical ground reaction force; anterior tibial shear force

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Injuries to the anterior cruciate ligament (ACL) are extremely costly, annually accounting for more than $3 billion in health care in the United States.[13,23] These injuries are associated with poor long-term consequences, including early onset of osteoarthritis and decreased participation in physical activity.[19,36] Therefore, preventing noncontact ACL injuries is crucial because of the public health impact associated with this injury. A recent systematic review of the literature revealed moderate evidence to support the use of injury prevention programs for reducing rates of ACL and other lower-extremity injuries.[30]

Understanding the mechanisms of injuries is an important aspect of preventing them.[1] Most ACL injuries occur when an individual is either landing from a jump or decelerating while changing direction.[3] Injury to the ACL occurs when the applied load exceeds the overall strength of the ligament. The ACL experiences the greatest loading when anterior tibial shear is applied in combination with internal-external rotation and/or valgus-varus moments.[2,21] As a result, the ACL may be at greatest risk for injury during combined multiplanar loading. Anterior tibial shear (sagittal plane) is considered the most direct loading mechanism.[21,22] Decreasing anterior tibial shear through ACL injury prevention programs is one method to minimize ACL loading and thereby reduce injury risk. This review is not meant to downplay the role of knee valgus and tibial rotation, which can increase ACL loading[21]; however, it does focus on the sagittal plane.

A decreased knee flexion angle leads to greater anterior tibial shear by increasing the patellar tendon–tibial shaft angle.[27] As the patellar tendon–tibial shaft angle increases, the quadriceps-induced anterior tibial shear also increases.[18] Thus, small knee flexion angles may allow for greater quadriceps-induced anterior tibial shear. Decreased knee flexion also minimizes the hamstring's ability to produce posterior tibial shear, which can offset anterior tibial shear.[18]

Ground reaction forces during athletic tasks may also influence the magnitude of anterior tibial shear by affecting knee flexion-extension moments that must be balanced by the quadriceps and hamstrings muscles. Yu et al[38] demonstrated that increased posterior ground reaction force during a stop-jump task resulted in greater quadriceps muscle force and greater ACL loading. ACL loading during landing peaks at the time of maximum vertical ground reaction force (VGRF) immediately after initial contact.[4] Research by Yu et al revealed that peak posterior ground reaction force was simultaneous with peak VGRF.[38] More recently, Sell et al[34] reported that posterior ground reaction force and knee flexion moment were significant predictors of anterior tibial shear during a stop-jump task. These findings suggest that knee flexion angle, knee flexion-extension moment, and ground reaction forces are all important factors that influence the magnitude of anterior tibial shear.

Despite initial evidence regarding the use of injury prevention programs to decrease injury rates, there is a lack of consensus regarding the type of exercises and instructions that effectively alter these variables. Therefore, the purpose of this systematic literature review was to answer the following question: Can ACL injury prevention programs alter lower-extremity sagittal plane kinematics, kinetics, and ground reaction forces?

METHODS

Data Sources

We performed an electronic literature search of the PubMed database, maintained by the National Library of Medicine, for articles matching our criteria, published between January 1988 and June 2008. We searched the database using variations of the following terms: *healthy*, *athlete*, *sport*; *injury prevention*, *anterior cruciate ligament injury prevention*, *knee injury*; *landing force*, *plyometric*, *strength*, *kinematic*, *balance*, *proprioception*, *movement*, *technique*, *muscle activity*, and *landing pattern*. This search identified a total of 247 articles.

Study Selection

Selection included the following criteria: written in English, comprised a healthy patient population, and addressed at least 1 of 3 factors (lower-extremity sagittal plane kinematics, kinetics, or ground reaction forces). The programs under study had to incorporate flexibility, balance, agility, strength, or plyometric exercises to modify potential neuromuscular risk factors for lower-extremity injury. In addition, programs had to incorporate multiple training sessions to be included in the review. Seven articles met this requirement. The reference lists of these articles were also reviewed for additional studies that met our criteria, and 2 such studies were identified. A total of 9 studies were included in this systematic review.

Data Extraction

Details were extracted from each study: target population, exercise components, duration, frequency, method of instruction, and supervision. Both authors independently verified data extraction.

Data Synthesis

Both authors evaluated the quality of the study design, blindly, via the PEDro Scale (10 points for supreme design and methods quality).[20] Scoring discrepancies were resolved by discussion. PEDro effect sizes were calculated from the means and standard deviations. Effect sizes greater than 0.70 were rated *strong*; 0.41 to 0.70, *moderate*; and less than 0.40, *weak*.[6]

RESULTS

A variety of exercises were used across the 9 studies to modify sagittal plane knee biomechanics and VGRF. The majority of the studies used an "integrated" training program, involving multiple exercises[5,14,17,25,26,31]; usually, a combination of strength, balance, and plyometric exercises was used during a single training session. Two of the studies used an "isolated" training approach, used just one type of exercise over the course of the program. One study used only plyometric training,[16] whereas another used only strengthening (Thera-Band resistance using concentric and eccentric contractions).[12] The training regimen influenced the success of the program, as did technique instruction and feedback for proper technique, as well as direct supervision.

Table 1. Results of studies investigating the effectiveness of anterior cruciate ligament injury prevention programs on anterior tibial shear force and knee flexion-extension moments.

Study	Task[a]	Outcome	Change (%)[b,c]	Effect Size[c]
Herman et al[12]	SJ	Decreased anterior tibial shear force	–3.70	0.09
Lephart et al[17]	VJ	Decreased external knee flexion in plyometric group[d]	–22.40	0.45
		Decreased external knee flexion in basic resistance group[d]	–35.40	0.60
Chappell, Limpisvasti[5]	DJ	Decreased external knee flexion moment[d]	–21.10	0.42
	SJ	No significant change	–9.80	0.11
Hewett et al[14]	VJ	No significant change	NA	NA
Herman et al[12]	SJ	No significant change	–3.60	0.11

[a]SJ, stop-jump; VJ, vertical jump; DJ, drop jump.
[b]Negative percentage change indicates decreased anterior tibial shear force or knee flexion moment.
[c]NA, not available (ie, means and measures of variability were not provided in the study).
[d]Indicates significant change following completion of injury prevention program.

Sagittal Plane Knee Kinetics

The sagittal plane knee kinetic variables investigated included proximal anterior tibial shear force (PATSF)[12] and knee flexion-extension moment.[5,12,14,17] Four articles met the inclusion criteria (mean PEDro score, 6.25; see Table 1).[5,12,14,17]

Herman et al,[12] using a cohort design, investigated the influence of 9 weeks of isolated strength training (quadriceps, hamstrings, gluteus medius, and gluteus maximus muscles) on PATSF values (PEDro, 7.00). College-aged recreational athletes performed the strength training program 3 times per week and were required to complete at least 23 of the 27 sessions (85%) for inclusion in the study. Exercises were performed using Thera-Band tubing for resistance—specifically, 3 sets of each exercise, with 8 to 12 repetitions per set. Once 12 repetitions of an exercise could be performed, the level of resistance was increased by 10%. Results indicate that PATSF values during a stop-jump task were not changed following a 9-week program.

Four studies investigated the effects of the programs on knee flexion-extension moments.[5,12,14,17] Herman et al revealed that isolated strength training did not affect internal knee extension moments at the time of peak PATSF during the landing phase of a stop-jump task.[12] Similarly, Hewett et al,[14] in a 1-way repeated measures design (no control group), investigated the effects of a 6-week integrated jump training program on external knee flexion and extension moments during a vertical jump (PEDro, 6.00). The participants were high school–aged female volleyball athletes who trained approximately 2 hours a day, 3 days a week. There was a small decrease in external knee flexion-extension moments, but these changes were not statistically significant. Effect sizes were not reported and were unable to be calculated.

Two studies did demonstrate significant changes in knee flexion-extension moment following a prevention program. Lephart et al,[17] in a randomized trial design (PEDro, 7.00) assigned high school females to either an 8-week plyometric or a basic strength training program (no control group). The latter group performed flexibility, balance, and strength exercises. The plyometric training group followed the basic strength training group during weeks 1 to 4 but during weeks 5 to 8 performed plyometric and agility exercises. A significant decrease in external knee flexion moment during a vertical jump task was reported for both groups, with no difference between the groups.

Chappell and Limpisvasti[5] performed a 1-way repeated measures design study of knee moments (no control group) and hence showed significant decreases in external knee flexion moments (PEDro, 5.00). Division I soccer and basketball athletes participated in a 6-week daily training program before their regular practice sessions (6 days of training per week). Ten exercises—including balance, core stability, lower-extremity strengthening, plyometric exercises, and agility—were performed over a 10- to 15-minute training session. Drop jump testing revealed a significant decrease in external knee flexion moment, with no significant change during the stop-jump task.

Isolated strength training does not appear to influence PATSF, according to the only study designed to address that issue.[12] Note, however, that only 1 study has investigated PATSF.

The effect of ACL injury prevention programs on knee flexion-extension moments is less clear. Isolated training programs, such as strength[12] or plyometric training,[14] did not demonstrate improvements in knee flexion-extension moment. However, integrated programs that involved some combination of balance exercises and strength and plyometric exercises were able to decrease external knee flexion moments.[5,17]

Table 2. Results of studies investigating the effectiveness of anterior cruciate ligament injury prevention programs on vertical ground reaction force (VGRF).

Study	Task[a]	Outcome	Change (%)[b]	Effect Size
Hewett et al[14]	VJ	Decreased VGRF[c]	–18.0	0.87
Prappavessis et al[33]	DL	Decreased VGRF[c]	–33.3	0.79
Irmischer et al[16]	DL	Decreased VGRF[c]	–26.4	1.4
Herman et al[12]	SJ	No significant change	–3.1	0.07
Chappell, Limpisvasti[5]	SJ	No significant change	1.6	0.07
	DJ	No significant change	8.5	0.28
Lephart et al[17]	VJ	No significant change for basic resis-tance group	–4.2	0.14
		No significant change for plyometric group	–4.1	0.12

[a]VJ, vertical jump; DL, drop land; SJ, stop jump.
[b]Negative percentage change indicates decreased VGRF; positive percentage change indicates increased VGRF.
[c]Indicates significant change following completion of injury prevention program.

VGRF

Six studies met the inclusion criteria regarding VGRFs (mean PEDro score, 6.25).[5,12,14,16,17,33] Table 2 presents summaries of the findings from each article studying VGRF.

The study findings were not consistent. Three studies demonstrated no significant changes in VGRF,[5,12,17] whereas 3 revealed significant reductions in VGRF following completion of a prevention program.[14,16,33] The studies that found no change in VGRF were described previously: Lephart et al[17] reported no change in VGRF for either the basic strength training group or the plyometric training group; more recently, Herman et al[12] and Chappell and Limpisvasti[5] confirmed these findings by demonstrating no change in VGRF following isolated strength training programs and integrated training programs (plyometric, strength, and balance exercises), respectively.

In contrast, 3 studies revealed large statistically significant reductions in VGRF following the completion a prevention program.[14,16,33] As previously described, Hewett et al[14] incorporated a 6-week integrated training program, during which participants consistently received considerable verbal instruction and feedback regarding their jump performance—specifically, "on your toes," "straight as an arrow," "light as a feather," "shock absorber," and "recoil like a spring." Also, all exercise sessions were supervised to monitor compliance and technique.

Irmischer et al[16] and Prapavessis et al[33] also reported large statistically significant decreases in VGRF. In a randomized controlled trial (PEDro, 6.00), a 4-phase jump-training program with plyometric exercises was performed 2 times per week over a 9-week training period under direct supervision. As the phases progressed, the intensity of the exercises increased. One of the major components of this program was that of focused instruction on proper lower-extremity positioning during landing. Participants were instructed to land as softly and quietly as possible.

Prapavessis et al also performed a randomized controlled trial, during which school-age children (8-10 years old) underwent 5 training and testing sessions. Participants were tested daily, before and after training sessions, for 4 days. During session 1, both the control group and the intervention group were instructed to land as softly as possible, before and after each single-leg drop landing. During sessions 2 to 4, the control group was instructed to land as softly as possible, whereas the intervention group was given a set of specific instructions: "Position yourself on the balls of your feet with knees bent just prior to landing, then lower the heels slowly to the ground keeping your knees bent until well after landing. Use the sound of your landing to tell you how softly you landed." Both the control and intervention participants were instructed to "land as softly as possible." Session 5 was completed 3 months after session 4 and thus served as a retention test.

The programs used by Irmischer et al and Prapavessis et al were similar to that of Hewett et al in that they centered on proper technique with instruction and direct supervision during training sessions. The large reductions in VGRF following training were similar to those of Hewett et al.

Although the results of the 6 studies are not consistent, the distinct differences between them explain the findings. Each study that demonstrated significant decreases in VGRF (following training) utilized verbal instructions and feedback for proper landing technique, auditory cues for minimizing landing forces, and performance under direct supervision. In contrast, those studies indicating no change in VGRF did not incorporate regular verbal or auditory feedback and performance under direct supervision on a regular basis.

As such, ACL injury prevention programs that incorporate verbal and auditory feedback and performance under direct supervision are able to demonstrate large reductions in VGRF (range, 18%–38%). Furthermore, the reductions in VGRF when using these techniques seem clinically important given the large associated effect sizes (range, 0.56–1.40).

Sagittal Plane Knee Kinematics

Seven of the 9 articles included in this review evaluated the potential to change sagittal plane knee kinematics through ACL injury prevention training. Kinematics were assessed by 3 variables: knee flexion angle at initial contact,[5,17,25] peak knee flexion angle during stance,[5,12,14,17,25,31] and knee flexion angular displacement.[26] The average PEDro score for these 7 studies was 5.71, with the majority of the studies showing positive results (see Table 3).

Four of the 7 studies improved at least 1 knee flexion angle variable following completion of the program.[5,17,25,26] As previously described, Chappell and Limpisvasti's integrated training program produced a significant increase in knee flexion angle at initial contact (5.0°) when participants performed a drop jump task.[5] During the stop-jump task, knee flexion angle did not increase significantly at initial contact (1.6°). Peak knee flexion angle did increase (5.6°) but not during the stop-jump.

Knee flexion angle improvements have also been observed in high school athletes with prevention programs. Lephart et al[17] reported significant increases in peak knee flexion angle during a vertical jump following strength and plyometric training. Although peak knee flexion angles increased, there were no significant changes in knee flexion angle at initial contact.

Myer et al[25] used a randomized controlled trial of female high school volleyball players to evaluate a plyometric training group and a dynamic stabilization (balance) training group. The plyometric training group performed jumping and cutting exercises with maximum effort, whereas the dynamic stabilization group concentrated on landing on stable and unstable surfaces. Both groups trained 90 minutes per day, 3 days per week for 6 weeks, incorporating strength training, technique instruction, and feedback. Technique instruction and feedback were different between groups, however. The plyometric training group was instructed to improve its speed and efficiency, whereas the dynamic stabilization training group was encouraged to improve knee flexion. The plyometric training program significantly increased knee flexion at initial contact and peak knee flexion during a drop jump task but not during a single-leg medial drop landing task. In contrast to the plyometric training group, the dynamic stabilization group (with balance and strengthening exercises) significantly improved peak knee flexion during the medial drop landing task but not during the drop jump task. Myer et al[26] observed similar significant improvements in a comparable program, in terms of duration and frequency.

Unfortunately, no means and measures of variability were reported in either of these 2 studies; as such, calculations of effect sizes were not possible. Despite the successes demonstrated in these programs, 3 studies failed to see any improvements in knee flexion angle following a prevention program.[12,14,31] A common finding in these 3 studies was that balance exercises were absent[12,31] or were a minor component.[14]

DISCUSSION

Our systematic review of sagittal plane studies of ACL injury prevention programs demonstrates that there is a moderate level of evidence to support the use of integrated programs involving balance, plyometric training, strength, flexibility, and feedback/instruction to increase knee flexion angle

Table 3. Results of studies investigating the effectiveness of anterior cruciate ligament injury prevention programs on knee flexion angle.

Study	Task[a]	Outcome	Change (%)[b,c]	Effect Size[c]
Chappell, Limpisvasti[5]	DJ	Increased knee flexion at initial contact[d]	17.4	0.58
		Increased peak knee flexion[d]	6.9	0.53
	SJ	No significant change in knee flexion at initial contact	4.4	0.17
		No significant change in peak knee flexion	–2.7	0.19
Lephart et al[17]	VJ	No significant change in knee flexion at initial contact for plyometric group	–16.1	0.36
		No significant change in knee flexion at initial contact for basic resistance group	4.8	0.07
		Increased knee flexion at initial contact for plyometric group[d]	38.8	0.68
		Increased knee flexion at initial contact for basic resistance group[d]	12.5	0.4
Pollard et al[31]	DJ	No significant change in peak knee flexion	–5.2	0.26
Herman et al[12]	SJ	No significant change in peak knee flexion	–9.9	0.46
Hewett et al[14]	VJ	No significant change in peak knee flexion	–1.2	0.17
Myer et al[25]	DJ	Increased knee flexion at initial contact for plyometric group[d]	NA	NA
		No significant change in knee flexion at initial contact for balance group	NA	NA
		Increased peak knee flexion for plyometric group[d]	NA	NA
		No significant change in peak knee flexion for balance group	NA	NA
	1-LMDL	No significant changes in knee flexion at initial contact for plyometric group	NA	NA
		No significant change in knee flexion at initial contact for balance group	NA	NA
		No significant change in peak knee flexion for plyometric group	NA	NA
		Increased peak knee flexion for balance group[d]	NA	NA
Myer et al[26]	DJ	Increased knee flexion range of motion[d]	8.4	NA

[a]DJ, drop jump; SJ, stop-jump; VJ, vertical jump; 1-LMDL, 1-leg medial drop land.
[b]Positive percentage change indicates increased knee flexion angle; negative percentage change indicates decreased knee flexion angle.
[c]NA, not available (ie, means and measures of variability were not provided in the study).
[d]Indicates significant change following completion of injury prevention program.

and decrease external knee flexion moment and VGRF. This recommendation is based on a limited number of inconsistent and moderate-quality studies. Unfortunately, there is no evidence to indicate that these programs may decrease PATSF. The only study to date to investigate the effects of a prevention program (isolated strength training) on PATSF found no significant improvements.[12]

All the reports included in this systematic review had PEDro scores of 7.00 or below, with an average score of 5.90 (range, 3.00–7.00). Three studies were randomized controlled trials that investigated 2 intervention groups.[17,25,33] None of the studies of integrated injury prevention programs used a true control group, where participants did not undergo any form of intervention. The lack of a true control group is a major limitation in this research.

The prevention studies did not demonstrate a negative effect on sagittal plane knee biomechanics or VGRF.[†] Thus, although not all programs appear to yield statistically significant improvements in these variables, there is no evidence to suggest that the ACL injury prevention programs cause harm. Overall, the results from each study suggest that sagittal plane knee biomechanics and VGRF either improved or tended to improve following an ACL injury prevention program—namely, in the form of decreased PATSF, external knee flexion moment, VGRF, and/or increased knee flexion angle.

A limitation of this systematic literature review is its focus on sagittal plane biomechanics and ground reaction force data. This choice was made, however, for two reasons. First, the majority of research available examined sagittal plane factors. Second, cadaver research implicates proximal anterior tibial shear force as the most direct ACL loading

[†]References 2, 9, 17, 26, 30, 34, 36, 37.

mechanism.[11,21] Although knee valgus and tibial axial rotation can increase ACL strain, the magnitude is smaller in comparison to that of anterior tibial shear.[21] The lack of discussion on frontal and transverse plane biomechanics does not suggest that these variables are unimportant for ACL injury prevention. The ability to successfully modify specific frontal and transverse plane biomechanics (eg, knee valgus angle and moment, tibial rotation angle and moment) may be essential components to decreasing the risk of ACL injury.

VGRF

There is strong evidence to indicate that VGRF can be reduced with proper instruction on jumping and landing technique and with direct supervision. Each study that demonstrated significant decreases in VGRF incorporated technique instruction and trained professional supervision and feedback.[14,16,33] Those studies that did not incorporate technique instruction and training session supervision failed to significantly decrease VGRF.[5,12,17] ACL injury prevention programs should include proper technique instruction, and they should be performed under the supervision of trained professionals who provide feedback on movement quality during the exercise sessions.

Previous research demonstrated reductions in VGRF following a single session of instruction (augmented feedback), whether verbal, visual, or both.[7,24,28,29,32] Cowling et al[7] and Onate et al[28] both demonstrated significant increases in knee flexion and increased hamstrings muscle activation following a single session of instruction, similar to those reporting decreased VGRF.[14,16,33] In fact, the increased knee flexion may have facilitated the decreased VGRF. An inverse relationship between VGRF and knee flexion angle/displacement during landing tasks has been identified.[8-10]

Knee Flexion Angle

The combination of balance training and strength training is needed to increase knee flexion angle during jumping and landing tasks. Five of the 6 programs demonstrating an increase in knee flexion used a combination of multiple balance and strength exercises.[5,17,25,26] In contrast, programs that used an isolated training approach[12] or an integrated program with only a single balance exercise[14] did not improve knee flexion. Only 1 program (plyometric and strength[25]) improved knee flexion angle without balance exercises. This combination did not improve knee flexion angle during a drop jump task, but it did improve it during a medial drop land task.

The combination of balance and strength training may successfully increase knee flexion angle through a variety of mechanisms, including increasing muscle force capacity.[12] Balance training may facilitate increased knee flexion by lowering the body's center of mass while increasing muscle coactivation. The body's center of mass may be lowered by flexing knees, hips, and trunk to improve postural stability and maintain balance. Perturbation training and exercises that require balancing on a single leg have increased antagonist coactivation of the knee flexor muscles,[15,35,37] which may produce greater knee flexion.

Anterior Tibial Shear and Knee Flexion-Extension Moment

Integrated training with multiple balance exercises becomes important when attempting to improve sagittal plane knee kinetics. Herman et al[12] incorporated isolated strength training, whereas Hewett et al[14] used integrated training with a single balance exercise. Neither of these studies improved PATSF[12] or knee flexion-extension moment.[12,14] In contrast, external knee flexion moment was significantly decreased by those programs that included an integrated protocol of balance exercises with strength and plyometric training.[5,17] Lephart et al[17] demonstrated the same improvement in external knee flexion moments in participants who focused on balance and strength exercises, compared to those who performed balance, strength, and plyometric exercises. Therefore, balance exercises appear to be important for decreasing external knee flexion moments.

Even though isolated strength training did not improve sagittal plane knee kinetics and VGRF, the benefits of strength training should not be discounted. Strength may be necessary to modify sagittal plane knee biomechanics and VGRF, but it may not be sufficient in isolation.[12] Balance and plyometric training may be required to improve muscle force capacity and alter neuromuscular control strategies.

Task Demands in ACL Injury Prevention Programs

Sagittal plane knee biomechanics and VGRF monitoring may be dependent on the testing format. In 2 studies of the stop-jump task,[5,12] there were no significant changes in sagittal plane biomechanics or VGRF after the prevention programs. Those studies showing improvements used lower-energy tasks for testing: drop land,[16,33] drop jump,[5,25,26,31] vertical jump,[14,17] and medial drop landing.[25] The lack of sagittal plane improvements in the Herman and Chappel training programs is puzzling, but it could be due to the training exercises or the testing task. In

Clinical Recommendations

SORT: Strength of Recommendation Taxonomy

A: consistent, good-quality patient-oriented evidence

B: inconsistent or limited-quality patient-oriented evidence

C: consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
Anterior cruciate ligament injury prevention programs should incorporate an integrated training approach comprising multiple exercise types to improve sagittal plane knee biomechanics.	C
Anterior cruciate ligament injury prevention programs should be performed under the supervision of trained personnel who provide feedback on movement quality during performance of exercises.	C
To increase knee flexion angle, a combination of balance and strength training exercises should be performed.	C

For more information about the SORT evidence rating system, see www.aafp.org/afpsort. xml and Ebell MH, Siwek J, Weiss BD, et al. Strength of Recommendation Taxonomy (SORT): a patient-centered approach to grading evidence in the medical literature. *Am Fam Physician.* 2004:69:549-557.

other words, prevention programs may successfully alter easy tasks, but the improvement may not transfer to more demanding tests (stop-jump). These programs may be best served by a range of difficulty, including jumping and cutting tasks.

CONCLUSION

There is moderate scientific evidence (based on inconsistent or limited-quality studies) that integrated programs of instruction/feedback, balance, plyometric, and strengthening can improve sagittal plane knee biomechanics. However, there is strong scientific evidence (based on consistent and high-quality studies) to support the use of trained personnel who provide instructions and feedback on proper movement technique during training (ie, direct supervision) to decrease VGRF.

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