The Effect of Weak Hip Abductors or External Rotators on Knee Valgus Kinematics in Healthy Subjects: A Systematic Review

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Context: It has been postulated that subjects with weak hip abductors and external rotators may demonstrate increased knee valgus, which may in turn raise risk of injury to the lower extremity. Recent studies have explored the potential link between hip strength and knee kinematics, but there has not yet been a review of this literature. Objective: To conduct a systematic review assessing the potential link between hip-abductor or external-rotator strength and knee-valgus kinematics during dynamic activities in asymptomatic subjects. Evidence Acquisition: An online computer search was conducted in early February 2011. Databases included Medline, EMBASE, CINAHL, SPORTDiscus, and Google Scholar. Inclusion criteria were English language, asymptomatic subjects, dynamometric hip-strength assessment, single or multicamera kinematic analysis, and statistical analysis of the link between hip strength and knee valgus via correlations or tests of differences. Data were extracted concerning subject characteristics, study design, strength measures, kinematic measures, subject tasks, and findings with regard to correlations or group differences. Evidence Synthesis: Eleven studies were selected for review, 4 of which found evidence that subjects with weak hip abductors or external rotators demonstrated increased knee valgus, and 1 study found a correlation to the contrary. Conclusions: There is a small amount of evidence that healthy subjects with weak hip abductors and perhaps weak external rotators demonstrate increased knee valgus. However, due to the variation in methodology and lack of agreement between studies, it is not possible to make any definitive conclusions or clinical recommendations based on the results of this review. Further research is needed.

Keywords: functional rehabilitation, health care, injury management, sport management, physical therapy

In recent years, there has been increased interest in the relationship between hip-abductor or external-rotation strength and lower extremity injuries. Evidence suggests that a relationship exists between hip strength and injuries such as patellofemoral pain syndrome,1–6 iliotibial band syndrome,7 ankle sprains,8,9 and lower extremity injury in general.10,11 Such studies are correlative and are therefore not able to differentiate whether the observed muscle weakness is the cause of the injury or whether it occurs as a result of some mechanism of inhibition or compensation by the body in response to pain. One prospective study, using regression analysis, found that hip external-rotation weakness was more prevalent in basketball and track athletes who would suffer an in-season injury.12

Hip-abductor and external-rotator weakness may predispose the body to injury by altering trunk or lower extremity kinematics, resulting in increased mechanical stresses on various joints and soft tissues. Lateral trunk lean in subjects with weak hip abductors has been cited as a potential kinematic compensation that could lead to low back pain and injury.13 Hip-abductor and external-rotator weakness may permit excessive femoral internal rotation and adduction and diminished control of dynamic knee valgus, resulting in repetitive stress injuries such as patellofemoral pain14,15 and iliotibial band syndrome7,15 or traumatic injury such as noncontact anterior cruciate ligament rupture.16,17 Following the kinetic chain downward, increased knee valgus may result in increased pronation at the ankle, which has been associated with plantar fasciitis,18 Achilles tendinitis,19 tibial stress syndrome,20 and tibial stress fracture.21

Clinicians are increasingly prescribing hip-strengthening exercises to patients. It is not yet clear whether these exercises should be applied for injury prevention, rehabilitation, or both since the influence of hip strength on lower extremity kinematics is not yet well understood. It is also unclear whether the mechanism of influence might be directly a result of the action of the hip abductors and external rotators or via a synergistic effect on the larger thigh muscles or gluteus maximus.22,23

In recent years, several authors have published studies that have explored the hypothesis that subjects with weak hip abductors or external rotators demonstrate increased knee valgus. Studies have approached
the question in 2 main ways: assessment of correlation and assessment of group differences. There has been no systematic review of this literature to date.

**Objective**

There are 2 guiding questions in this systematic review: Is there a correlation between hip-abductor or external-rotator strength and knee-valgus kinematics in healthy subjects performing dynamic activities? Are there differences in knee-valgus kinematics between healthy subjects with abductors or external rotators of differing strengths when performing dynamic activities?

**Evidence Acquisition**

**Outcome Measures**

**Strength.** Use of dynamometry to assess muscle strength was deemed appropriate for studies included in this review. Isokinetic and handheld dynamometry have been shown to have high reliability in testing hip-abduction and external-rotation strength.6,13,24–30

**Kinematics.** Multicamera 3-dimensional (3D) or single-camera 2D kinematic analyses were deemed appropriate measures of kinematics for this review since both methods have been shown to be accurate and reliable measures of lower extremity motion in the frontal plane.31–35 McLean et al35 showed a moderate correlation between 2D frontal-plane motion analysis and 3D kinematic analysis of knee valgus when assessing side-step and side-jump movements in college basketball players. They maintain that multicamera 3D analysis is still the best test for assessing knee kinematics.

Electrogoniometry and electromagnetic motion tracking were not acceptable since sufficient evidence was not found demonstrating their accuracy and reliability. Reliability and concurrent validity of electrogoniometry have been shown in the sagittal plane56 but not in the frontal plane. Several studies have assessed the accuracy of electromagnetic motion tracking,37–40 but only 1 performed in vivo assessments at higher speeds.40 Although those researchers found accuracy similar to that found in previous studies under stable conditions, they found unacceptable levels of measurement error when measuring dynamic motions at speeds found in running or jumping.

**Study Search and Selection**

Both the literature search and the study-selection process were performed by the author. During the first 2 weeks of February 2011 a computer-based online literature search was performed using Medline (1950 to February 2011), CINAHL (1982 to February 2011), EMBASE (1980 to February 2011), and SPORTDiscus. Advanced searches used the keywords *hip strength, hip kinematics, knee kinematics, knee valgus,* and *strength.* Searches were limited to articles in English and human subjects. Google Scholar was also searched using the same keywords, and searches were limited to the first 15 pages of results. A summary of the search strategy is provided in Table 1.

Studies were selected if they assessed the relationship between hip strength and knee valgus or knee

**Table 1 Search Summary**

<table>
<thead>
<tr>
<th>Database</th>
<th>Search terms (keywords)</th>
<th>Yield</th>
<th>Qualified</th>
<th>Obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medline</td>
<td><em>hip strength</em></td>
<td>98</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td><em>hip kinematics</em></td>
<td>43</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td><em>knee valgus</em></td>
<td>83</td>
<td>4</td>
<td>3 (1 repeat)</td>
</tr>
<tr>
<td></td>
<td><em>knee kinematics and strength</em></td>
<td>30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CINAHL</td>
<td><em>hip strength</em></td>
<td>68</td>
<td>2</td>
<td>0 (2 repeat)</td>
</tr>
<tr>
<td></td>
<td><em>hip kinematics</em></td>
<td>18</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td><em>knee valgus</em></td>
<td>65</td>
<td>5</td>
<td>1 (4 repeat)</td>
</tr>
<tr>
<td></td>
<td><em>knee kinematics and strength</em></td>
<td>30</td>
<td>1</td>
<td>0 (1 repeat)</td>
</tr>
<tr>
<td>EMBASE</td>
<td><em>hip strength</em></td>
<td>102</td>
<td>3</td>
<td>0 (3 repeat)</td>
</tr>
<tr>
<td></td>
<td><em>hip kinematics</em></td>
<td>39</td>
<td>0</td>
<td>0</td>
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<td><em>knee valgus</em></td>
<td>83</td>
<td>5</td>
<td>0 (5 repeat)</td>
</tr>
<tr>
<td></td>
<td><em>knee kinematics and strength</em></td>
<td>41</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SPORTDiscus</td>
<td><em>hip strength</em></td>
<td>67</td>
<td>3</td>
<td>0 (3 repeat)</td>
</tr>
<tr>
<td></td>
<td><em>hip kinematics</em></td>
<td>24</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td><em>knee valgus</em></td>
<td>88</td>
<td>5</td>
<td>0 (5 repeat)</td>
</tr>
<tr>
<td></td>
<td><em>knee kinematics and strength</em></td>
<td>29</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Google Scholar</td>
<td>Same keywords as above</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Hand search</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>
frontal-plane motion OR conducted tests of kinematic differences in knee valgus or knee frontal-plane motion between weak and strong subjects AND were available as full-text articles rather than only abstracts or poster presentations, studied asymptomatic subjects, used the outcome measures described herein, and obtained informed consent as approved by an institutional ethical review board. Articles whose titles and abstracts suggested possible inclusion were obtained in full text for more detailed assessment of eligibility. Studies that met the selection criteria were subjected to a hand search for any relevant articles missed by the online search.

Studies were excluded if they assessed symptomatic patients, since pain avoidance, compensation, and inhibition were felt to be potential confounding factors in assessing the influence of strength on kinematics. In test–retest designs where subjects’ kinematics were tested before and after a strengthening protocol, studies were excluded if subjects were made to strengthen muscles other than the abductors and external rotators or if they were given coaching in proper movement strategy.44,45 While these are potential factors in creating kinematic changes in patients, they were felt to cloud the research question guiding this particular review. The excluded test–retest studies were also checked for any pretest data that might be relevant to the search question, but none were found. Two studies were excluded for not using the required kinematic outcome measures.

Data Extraction

Data were extracted, by the author, as they related to subject characteristics, study design, strength measures, kinematic methods, and subject tasks. Statistical data were extracted regarding (1) Pearson product–moment (PM) correlations (r values) between hip-abductor or external-rotator strength and knee kinematics and (2) group means and standard deviations for knee-valgus kinematics in comparisons between strong and weak groups.

Statistical Analysis

All statistical analyses were performed by a professional statistician. To calculate 95% confidence intervals that were not reported for Pearson PM correlations, a Fisher r-to-z transformation was calculated. Two-sided confidence limits for these z statistics were then calculated before transforming the limits back to reflect the limits around the r values. P values associated with Pearson r were calculated based on the transformed Fisher z. For the tests of differences, corresponding effect sizes (Cohen d) were calculated along with their 95% confidence intervals based on Hedges and Olkin.49

Assessment of Methodological Quality

Valid and reliable methodological quality-assessment tools that currently exist have been designed for use in appraising clinical trials. There are no established assessment tools for use in noninterventional studies such as those reviewed in this article.50,51 Assessment of the articles in this review was performed by the author and guided using a modified version of the instrument designed by Downs and Black.52 Modification involved dropping items that apply only to clinical trials or studies using control groups. Variations of this method have been used by previous authors,53,54 but their efficacy is not established. Although the original version was shown to be valid and reliable, readers should not presume that it retains its psychometric properties in its altered state. It is used here as a guide to assessing the reviewed articles.

Level of Evidence and Strength of Recommendations

The Oxford Centre for Evidence-Based Medicine levels of evidence table was used to assess the levels of evidence of the studies represented in this review and the strength of recommendations that could be made based on their evidence.

Evidence Synthesis

Final selection resulted in 11 studies for review, all of which were published from 2005 to 2010.25–28,30,56–61 Table 2 lists the main characteristics of each study, which are also described in the following sections.

Subject Characteristics

Ten of the studies used college-age subjects, and 1 used teen-age subjects.59 Six studies used recreationally active subjects,1,25,26,28,57,60 1 used officer cadets,64 1 used varsity athletes,30 1 used high school soccer players,59 and 2 did not specify.27,56 Six studies involved only female subjects,25,28,57,60; 5 involved both male and female subjects.26,27,30,56,61

Design of Studies

Seven of the studies used a cross-sectional design to assess the correlation of hip strength with knee kinematics.26,27,30,56,58,59,61 Those 7 assessed correlations with hip-abductor strength, and 5 of them assessed correlations with hip-external-rotator strength.30,56,58,59,61 One assessed correlations both before and after a hip-abductor fatigue protocol.27

Five studies assessed kinematic differences between groups with differing hip strength.25,27,28,57,60 Two made comparisons between designated strong and weak groups, 1 selecting the 15 weakest and 15 strongest subjects from a sample of 110 and the other selecting the weakest and strongest quartiles of 72 test subjects.28 The remaining 3 assessed groups of differing hip strength either by comparing kinematics before and after isolated abductor fatigue27,57 or by comparing kinematics in a group before...
<table>
<thead>
<tr>
<th>Study</th>
<th>Subject characteristics</th>
<th>Design</th>
<th>Kinematic measures</th>
<th>Strength measures</th>
<th>Subject tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geiser et al(^{57})</td>
<td>20 F. Mean age 20.7 y. Recreationally active.</td>
<td>Test–retest of subjects before and after a fatigue protocol</td>
<td>3D hip abd/add, knee valgus/varus</td>
<td>Isometric peak torque, isokinetic dynamometer, hip abd</td>
<td>1-leg drop and cut, 1-leg drop and 1-leg jump, 1 leg drop-and-run</td>
</tr>
<tr>
<td>Heinert et al(^{25})</td>
<td>30 F: 15 weak, 15 strong. Age 21–49. Recreationally active.</td>
<td>Observational prospective comparison of kinematics between strong and weak subjects</td>
<td>3D hip abd/add, knee valgus/varus, knee flexion, lateral pelvic tilt</td>
<td>Isometric peak torque, handheld dynamometer anchored, hip abd</td>
<td>Running</td>
</tr>
<tr>
<td>Hollman et al(^{58})</td>
<td>20 F. Mean age 24 y. Recreationally active.</td>
<td>Cross-sectional</td>
<td>2D hip abd/add, knee valgus/varus</td>
<td>Isometric PT, handheld dynamometer, hip abd, hip ER</td>
<td>2-s step-down</td>
</tr>
<tr>
<td>Jacobs and Mattacola(^{26})</td>
<td>8 M, 10 F. Mean ages 22.1, 24.1 y. Recreationally active.</td>
<td>Cross-sectional</td>
<td>3D hip IR/ER, hip abd/add, hip flexion, knee valgus/varus, knee ER</td>
<td>Eccentric PT, isokinetic dynamometer, hip abd</td>
<td>1-leg hop and 1-leg landing</td>
</tr>
<tr>
<td>Jacobs et al(^{27})</td>
<td>15 M, 15 F. Mean ages 24.4, 23.2 y. Activity level not specified.</td>
<td>Cross-sectional and test–retest of subjects before and after a fatigue protocol</td>
<td>3D hip IR/ER, hip abd/add, hip flex, knee valgus/varus, knee flex, knee ER</td>
<td>Isometric PT, isometric endurance, isokinetic dynamometer, hip abd</td>
<td>2-leg hop and 1-leg landing</td>
</tr>
<tr>
<td>Lawrence et al(^{28})</td>
<td>32 F: 16 weak, 16 strong. Mean age 21 y. Recreationally active.</td>
<td>Observational prospective comparison of kinematics between strong and weak subjects</td>
<td>3D hip abd/add, hip flex, knee valgus/varus, knee flex</td>
<td>Isometric PT, handheld dynamometer with strap, hip ER</td>
<td>1-leg drop and 1-leg landing</td>
</tr>
<tr>
<td>Sigward et al(^{59})</td>
<td>39 F. Mean age 15.5 y. Soccer players.</td>
<td>Cross-sectional</td>
<td>3D knee valgus/varus</td>
<td>Isometric PT, handheld dynamometer with strap, hip abd, hip ER, hip ext</td>
<td>2-legged drop landing</td>
</tr>
<tr>
<td>Snyder et al(^{60})</td>
<td>13 F. Mean age 21.9 y. Moderately active.</td>
<td>Assessed kinematics both before and after a 6-wk hip-strengthening program</td>
<td>3D hip IR/ER, hip abd/add, knee valgus/varus</td>
<td>Isometric PT, handheld dynamometer with strap, hip abd, hip ER</td>
<td>Running</td>
</tr>
<tr>
<td>Thijs et al(^{61})</td>
<td>76 M, 8 F. Mean age 19.2 y. Officer cadets.</td>
<td>Cross-sectional</td>
<td>2D knee valgus/varus</td>
<td>Isometric PT, handheld dynamometer, hip abd/add, hip ER/IR, hip flex/ext</td>
<td>Forward lunge</td>
</tr>
<tr>
<td>Wilson et al(^{30})</td>
<td>22 M, 22 F. Mean ages 19.9, 19.4 y. Division 1A/1AA varsity athletes.</td>
<td>Cross-sectional</td>
<td>2D knee valgus/varus</td>
<td>Isometric PT, handheld dynamometer with strap, hip abd, hip ER, knee flex/ext, trunk ext/flex, side bridge</td>
<td>Single-leg squat</td>
</tr>
</tbody>
</table>

Abbreviations: M, male; F, female; PT, peak torque; IR, internal rotation; abd, abduction; add, adduction; ER, external rotation; ext, extension; flex, flexion.
and after a 6-week strengthening program targeting only the hip abductors.60

**Strength Measures**

All studies measured hip-abduction strength; however, one28 did not use abductor strength as a variable for kinematic comparison. Seven studies measured hip external-rotator strength.28,30,56,58–61 Various other muscles were measured for strength and are described in Table 2.

Muscle testing was performed using dynamometry in all studies. Four studies measured strength using isokinetic dynamometry,26,27,56,57 2 of which tested abduction in the standing posture26,56; 4 used a handheld dynamometer stabilized with a strap28,30,59,60; 1 used a handheld dynamometer with an anchoring station25; and 2 used a handheld dynamometer without added stabilization.58,61 Eight studies measured strength via isometric peak torque,25,28,30,57–61 1 used both isometric peak torque and isometric endurance,27 1 used eccentric peak torque,26 and 1 used both concentric and eccentric peak torque.56 All studies normalized strength measures to subject body mass, which Bazett-Jones et al62 found to be the most effective method of removing the influence of subject body size when comparing subjects of different sizes.

**Kinematic Measures**

Three studies chose peak knee-valgus angle26–28 as their measure of knee valgus, 3 chose frontal-plane projection angle,30,58,61 4 chose knee-valgus range of motion (ROM),25,57,59,60 and 1 study measured both valgus ROM and peak knee valgus.56 Various other kinematic movements were measured and are listed in Table 2. Tasks chosen for subjects to perform during kinematic analysis varied widely between studies and are summarized in Table 2. Eight studies measured 3D kinematics using 5 to 7 video cameras,25–28,56,57,59,60 Three studies measured 2D kinematics using a single camera.30,58,61

**Methodological Quality**

Table 3 summarizes the items that were retained from the original instrument and whether the reviewed studies met the criteria. Quality assessment was performed by a single reviewer. Two recent systematic reviews on methodological quality assessment caution against using numeric scores to compare study quality if a psychometrically verified instrument is unavailable.50,51 A summary score was therefore not included, but a brief review of how well the articles met the criteria is provided.

All studies met the criteria of adequately reporting their objectives, outcomes to be measured, and subject characteristics (items 1, 2, and 3). All used appropriate statistical analyses and valid and reliable outcome measures (items 18 and 20). None of the studies reported a selection process that ensured external validity as required by Downs and Black52 (items 11 and 12). However, the populations of active subjects, particularly women, are consistent with the populations of interest to clinicians with regard to this topic. None of the studies performed unplanned retrospective subgroup analyses (item 16).

Studies were scored on data reporting (items 6, 7, and 10) as they related to r values and group means. For tests of differences, estimates of random variability for group means were reported, and actual P values (not just the fact that they were less than .05) were provided in all cases. For Pearson PM correlations, actual P values were only reported in three30,59,61 of 7 studies, and confidence intervals for r values were not reported in any. One study reported only statistically significant r values.26 Three studies performed power calculations (item 27) before deciding on population sample sizes.57,58,60

**Data Synthesis**

The variation in methodology concerning subject tasks, dynamometry, and kinematic analysis make the direct comparison of results via forest plots or the use of

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**Table 3 Methodological Quality Assessment**

<table>
<thead>
<tr>
<th>Study</th>
<th>Item Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Claiborne et al56</td>
<td>1</td>
</tr>
<tr>
<td>Geiser et al.57</td>
<td>1</td>
</tr>
<tr>
<td>Heine et al25</td>
<td>1</td>
</tr>
<tr>
<td>Hollan et al58</td>
<td>1</td>
</tr>
<tr>
<td>Jacobs and Mattacola26</td>
<td>1</td>
</tr>
<tr>
<td>Jacobs et al27</td>
<td>1</td>
</tr>
<tr>
<td>Lawrence et al28</td>
<td>1</td>
</tr>
<tr>
<td>Sigward et al59</td>
<td>1</td>
</tr>
<tr>
<td>Snyder et al60</td>
<td>1</td>
</tr>
<tr>
<td>Thijs et al61</td>
<td>1</td>
</tr>
<tr>
<td>Wilson et al60</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: Modified from Downs and Black.54 1 = criterion met, 0 = criterion not met.
meta-analysis inappropriate. Data were therefore treated separately. Significant results are summarized in the following sections with regard to Pearson PM correlations ($r$ values) between hip strength and kinematics or effect sizes (Cohen $d$) for kinematic differences between strong and weak groups. Tables 4 and 5 list all correlations and Cohen $d$ values, respectively, for each study, along with 95% confidence intervals. Values were deemed significant ($P < .05$) if their confidence intervals did not cross zero.

**Relationship Between Hip Strength and Knee Valgus.** Of the 7 studies that assessed the relationship between hip-abductor strength and knee valgus, only Claiborne et al\textsuperscript{56} found a correlation consistent with the hypothesis. They found a weak to moderate negative correlation between concentric hip-abduction peak torque and valgus ROM in men and women performing a single-leg squat ($r = –.37$, $P = .047$, $r^2 = .14$). The $r^2$ value suggests that roughly 14% of the kinematic variance in knee valgus was explained by variation in hip-abductor strength. However, the other 3 correlations that they calculated for knee valgus and abductor strength were not significant. Contrary to the hypothesis, Hollman et al\textsuperscript{58} found a significant moderate positive correlation between isometric hip-abductor strength and frontal-plane knee-projection angle in women during stair descent ($r = .46$, $P = .0008$, $r^2 = .21$).

Of the 5 studies that assessed the relationship between hip external-rotation strength and knee valgus, 1 found a significant relationship. Willson et al\textsuperscript{30} found a moderate negative correlation between isometric hip external-rotator strength and knee frontal-plane projection angle in men and women performing a single-leg squat ($r = –.40$, $P = .007$, $r^2 = .16$). The $r^2$ value suggests that roughly 16% of the kinematic variation in knee valgus was explained by variation in hip external-rotator strength. The findings of the remaining studies did not reach statistical significance.

### Table 4 Pearson Correlation Coefficients Between Hip Strength and Knee Kinematics

<table>
<thead>
<tr>
<th>Study</th>
<th>Task</th>
<th>Strength measure</th>
<th>Hip-Abductor Strength</th>
<th>Hip External-Rotation Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Valgus ROM</td>
<td>Peak valgus/FPPA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Claiborne et al\textsuperscript{56}</td>
<td>1-leg squat</td>
<td>concentric</td>
<td>–.37 ($–.64$ to $–.005$)$^*$</td>
<td>–.17 ($–.50$ to $–.20$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>eccentric</td>
<td>–.25 ($–.56$ to $–.12$)</td>
<td>–.30 ($–.59$ to $–.07$)</td>
</tr>
<tr>
<td>Hollman et al\textsuperscript{58}</td>
<td>stair descent</td>
<td>isometric</td>
<td>.46 ($0.20$–$0.65$)$^†$</td>
<td>.12 ($–.63$ to $–.01$)</td>
</tr>
<tr>
<td>Jacobs and Mattacola\textsuperscript{26}</td>
<td>1-leg hop, 1-leg land</td>
<td>eccentric</td>
<td>–.61 ($–.89$ to $–.03$) women‡</td>
<td>did not report men</td>
</tr>
<tr>
<td>Jacobs et al\textsuperscript{27}</td>
<td>2-leg hop, 1-leg land</td>
<td>isometric</td>
<td>.09 ($–.44$ to $–.58$) men</td>
<td>–.35 ($–.73$ to $–.19$) women</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% isometric</td>
<td>–.38 ($–.75$ to $–.16$) men</td>
<td>–.30 ($–.60$ to $–.07$) all</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-leg land</td>
<td>–.22 ($–.66$ to $–.33$) women</td>
<td>–.15 ($–.48$ to $–.22$) all</td>
</tr>
<tr>
<td>Sigward et al\textsuperscript{59}</td>
<td>2-leg drop-land</td>
<td>isometric</td>
<td>–.11 ($–.41$ to $–.21$)</td>
<td>–.08 ($–.38$ to $–.24$)</td>
</tr>
<tr>
<td>Thij\textsuperscript{s161}</td>
<td>lunge</td>
<td>isometric</td>
<td>–.002 ($–.21$ to $–.22$)</td>
<td>–.05 ($–.26$ to $–.17$)</td>
</tr>
<tr>
<td>Wilson et al\textsuperscript{30}</td>
<td>1-leg squat</td>
<td>isometric</td>
<td>–.23 ($–.07$ to $–.49$)</td>
<td>–.4 ($–.62$ to $–.11$)$^*$</td>
</tr>
</tbody>
</table>

Abbreviations: ROM, range of motion; FPPA, frontal-plane projection angle.

$^*$Statistically significant Pearson correlation in support of hypothesis ($P < .05$). $^†$Statistically significant Pearson correlation contrary to hypothesis ($P < .05$).

‡Calculated 95%CI and $P$ value differ from authors’ reported $P$ value. Original $P$ value was based on a 1-sided calculation rather than 2-sided.
Effect of Hip Strength on Knee Valgus

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Kinematic Differences Between Weak and Strong Subjects. Of the 5 studies that explored group differences in kinematics, 2 found evidence to support the hypothesis. When comparing kinematics between pre-abductor-fatigued and post-abductor-fatigued subjects, Geiser et al. demonstrated that after a hip-abductor fatigue protocol women’s abductor strength was significantly reduced (pre = 102 ± 20 ft·lb, post = 64 ± 17 ft·lb; t = 13.58, P < .001). They found increased knee-valgus ROM in fatigued subjects performing a 1-leg drop to cutting maneuver, ES = 0.82 (95% CI, 0.17–1.46); 1-leg drop and jump, ES = 0.93 (95% CI, 0.28–1.58); and a 1-leg drop to running, ES = 0.72 (95% CI, 0.08–1.36). They noted this finding was in part due to fatigued subjects’ being positioned in a more abducted hip position and varus knee position at initial contact.

Heinert et al. compared running kinematics between a group of women with strong hip abductors and a weak group. The 2 groups represented the 15 strongest and 15 weakest of 110 subjects tested. The researchers found that the weak group demonstrated approximately 4° greater valgus angle (P = .008) for all stages of the stance phase than the strong group, ES = 0.84 (95% CI, 0.09–1.59). The findings of the remaining studies did not reach statistical significance.

Level of Evidence and Strength of Recommendation

These studies are based on principles of kinematic control via correlation or tests of difference in asymptomatic subjects. Therefore, based on the Oxford Centre for Evidence-Based Medicine levels of evidence table, evidence is limited to level 5, and any recommendations for clinical practice are limited to grade D.

Discussion

Of the 11 studies that explored hip-abductor weakness, 3 found statistically significant r values or Cohen’s d values that supported the hypothesis that subjects with abductor weakness demonstrate increased knee valgus. One study found an r value that contradicted this hypothesis. One discrepancy is noted in Table 4 between the statistical significance of the correlation reported by Jacobs and Mattacola and the calculated value in this review. According to Dr. Jacobs (written communication, December 2011), a 1-sided test was performed for their Pearson correlations. This explains why they reported a P value of .03 rather than the P value of .06 based on the 2-sided calculations performed in this review. Two-sided calculations were chosen for this review since they do not assume the direction of the correlation, allowing for the possibility of correlations contradictory to the posed hypothesis. Of the 7 studies that explored hip external-rotator weakness, 1 study found evidence that external-rotator weakness correlated with increased peak knee valgus.

There are several issues worth considering when interpreting the various studies’ findings: sample size, gender, task difficulty, types of kinematic measures, types of strength measures, nature of group differences, compensatory trunk motion, and kinematic correlations with other thigh muscles. Each is briefly discussed following.

Sample sizes were generally small in the reviewed studies. Only 3 studies used power analyses to determine their minimum sample size. Insufficient sample size would have the effect of reducing the statistical significance of the calculated r values and tests of differences. Some of the reviewed studies reported mild to moderate r values in support of the hypothesis that were

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<td>Pre vs post hip-abductor fatigue</td>
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<td>run</td>
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<td>Snyder et al.</td>
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Abbreviations: ROM, range of motion.

*Statistically significant effect size in group differences (P < .05).
not statistically significant.26,27,30,56 Some of these values may have reached statistical significance had the studies used larger sample sizes.

Previous literature has suggested that women demonstrate greater knee valgus than men performing the same tasks.53,63–65 Of the 5 studies that used both male and female subjects,26,27,30,56,61 only 2 treated their data separately.26,27 Combining males’ and females’ data may have had the effect of masking any potentially significant gender-specific effects. While Willson et al50 reported greater frontal-plane projection angle in women than men, they did not provide gender-specific r values, so the relative contribution of women to their reported r value for men and women combined is not clear.

It has been questioned whether tasks such as walking down 2 or 3 stairs, 1-legged squats, or utilizing a 2-legged stance are challenging enough to identify kinematic differences between weak and strong recreational athletes.41,57,59 Two of the 4 studies that found evidence to support the hypothesis used a single-leg squat.30,56 Neither of the 2 studies that used a 2-legged stance found support for the hypothesis.59,61 It is unclear whether there is a minimum level of task difficulty required for the study of knee-valgus kinematics. It is expected that a single-leg stance would increase the forces against which the abductors must stabilize compared with a 2-legged stance, as would jumping or cutting movements compared with low-impact tasks. Therefore, using tasks that are more difficult should help differentiate strength effects on kinematics by increasing the likelihood that the body’s ability to control valgus kinematics would be appropriately challenged. In addition, since the interests in knee-valgus kinematics relate to injury risk, the applicability of the research might be improved if the movements studied were comparable to those associated with lower extremity injury.

High-speed multicamera kinematic analysis has been reported to be a more accurate and reliable method for assessing 3D motions in the lower limb than single-camera 2D methods.35 Of the 4 studies that found evidence to support their hypotheses, 3 used 3D kinematic analysis.25,56,57 Despite its superiority, there has been recent evidence regarding limitations in the use of skin markers when using 3D kinematic analysis.66,67 Geiser et al57 acknowledged the possibility of measurement error via skin movement or systematic shift in marker position during a fatigue protocol. The significance of this is better appreciated when one considers that differences in ROM between their prefatigue and postfatigue subjects were smaller than the standard deviations in their measurement accuracy.

The studies reviewed did not measure hip strength in the same way. While isometric, eccentric, and concentric strength were all used by different researchers, most of the studies measured isometric peak torque. Snyder et al60 pointed out the potential compromise in validity when attempting to correlate anaerobic, isometric strength measures with dynamic, aerobic tasks. Considering the role of the hip muscles during weight acceptance, it is reasonable to consider eccentric peak torque a relevant measure to use; however, neither of the 2 studies in this review that assessed correlations with eccentric strength found a significant association.26,56

All the studies measured hip abduction in an open kinetic chain position. The 2 studies that tested standing hip abduction intended to measure the strength of the nonstance leg.26,56 Jacobs et al26 commented that this method of testing stresses the hip abductors bilaterally and so may lack validity. They also commented that the closed-chain demands on the stance leg may be more representative of the function of the hip muscles during landing, but a valid and reliable method of testing the hip abductors in a closed-chain position is not yet available. It is difficult, with standing dynamometry, to ensure that unilateral hip abduction is being isolated and therefore accurately tested. In a standing posture, the peak torque of the non-weight-bearing test leg may be affected by the ability of the opposite hip’s abductors to provide an adequate stabilizing counterforce. It is unclear to what degree asymmetry in hip-abductor strength would affect the results of the test. While this effect may be reduced in a side-lying position, it may still be a factor and might be reduced by ensuring that the upper body is stabilized against lifting off the test surface to reduce the demands on the nonetest leg against the test surface. Two of the reviewed studies appeared to account for this by placing a stabilizing strap around the subjects’ ribs.30,60

Studies that used tests of differences did not do so uniformly. Some compared upper and lower ends of a larger test group,25,28 while others used targeted fatigue25,57 or strengthening60 protocols to create groups of differing strengths. While using upper and lower percentiles seems the most valid, all these methods seem acceptable as long as the groups’ strength differences are quantified and, where interventions such as fatigue are used, are shown to be statistically significant. Of the 3 studies of group differences that used a fatigue or strengthening intervention,27,57,60 2 demonstrated that the 2 groups were significantly different in strength postintervention.57,60 The disadvantage of using upper and lower percentiles might be the high number of test subjects required to obtain the desired sample groups.

Ipsilateral trunk lean is acknowledged as a potential compensatory movement of subjects with weak hip abductors.13,42,58,68 In a 1-legged stance, ipsilateral trunk lean would move the center of body mass toward the stance leg, with the effect of reducing the external hip-adduction moment and therefore the demands on the hip-abductor muscle group. If subjects with weak hip abductors used this mechanism of compensation, it may reduce the effects of weak abductors on kinematics below the hip. None of the studies reviewed measured trunk kinematics to assess for compensatory lateral trunk lean to account for this potential confounding factor.

Observed correlations between kinematics and hip strength may be indicative of lower extremity muscle strength in general, not exclusively the abductors and external rotators. This would be more apparent if researchers assessed the relative influence of other leg
muscles. Four of the reviewed studies tested muscles other than the abductors and external rotators. Claiborne et al. found, using linear-regression analysis, that concentric abduction, knee flexion, and knee-extension peak torque were all significant predictors of frontal-plane motion. Also using linear-regression analysis, Willson et al. reported that external-rotation peak torque was the single biggest predictor of frontal-plane projection angle. Looking at strength ratios of various agonist–antagonist pairings, Thijs et al. found that the ratio of external rotation strength to internal rotation strength was the only significant predictor of knee-varus motion. Lawrence et al. found that knee-flexion synergistic effects with other muscles, neuromuscular analysis, Willson et al. reported that external-rotation extension peak torque were all significant predictors of frontal-plane motion. Also using linear-regression analysis, willson et al. reported that external-rotation strength was significantly different between weak and strong groups (P = .001) but did not perform a regression analysis. It is expected that other muscles of the lower extremity would influence knee valgus, and this would partly explain the relatively small r² values reported by Claiborne et al. and Willson et al.

It is important to remember that lower extremity kinematics may be influenced by many factors other than hip-abductor and external-rotator strength. Ankle pronation/eversion, bony anatomy, coactivation or synergistic effects with other muscles, neuromuscular training, movement-strategy instruction, sagittal-plane kinematics, movement anticipation, ground–shoe friction, incline of landing surface, and other external distractions have all been cited as potential influences on lower extremity frontal-plane kinematics.

Future Research

Larger sample sizes would help strengthen statistical analyses in future studies. At a minimum, power calculations should be done to guide study sample sizes. Since women and men have been shown to have differing kinematics, it would seem desirable to treat their data separately rather than combine them. In tests of kinematic differences where interventions are used to create groups of differing strengths, interventions should be isolated to the hip muscles, and strength differences should be quantified and shown to be statistically significant. Improved standardization of methodology relating to strength measures, kinematic analyses, and subject tasks would improve interpretation and comparison of future research by potentially allowing the use of forest plots or meta-analysis.

It is not clear from this review what the best method of strength assessment might be. Although it is tempting to think that eccentric peak torque or some measure of endurance may be the most relevant to dynamic and prolonged activities, this review did not provide evidence to support that notion. Isometric peak torque, particularly if using stabilized handheld dynamometry, may be more practical from a research perspective since it might allow larger, multisite, and clinic-based research to be performed. When using stabilized handheld dynamometry, the addition of a stabilizing strap across the chest as performed by Willson et al. or Snyder et al. might reduce demands on the contralateral hip abductors and provide results that are more accurate. Development of a valid and reliable method of measuring hip-abductor strength in a closed chain may be valuable.

At present, multicamera 3D motion analysis seems to be the most accurate and reliable method of measuring hip and knee kinematics in the frontal plane. If 2D motion analysis is to be used, McLean et al. suggests using tasks where the subject remains facing the camera and cautions that 2D analysis has reduced accuracy when tasks involve directional change, such as a cutting maneuver, due to the difficulty in accurately estimating joint centers.

Subject tasks should be demanding and should reflect movement in sport. For this reason, running, cutting, and 1-legged landing tasks intuitively seem appropriate, although, as already stated, the results of this review are insufficient to strengthen this view. In addition, the use of kinematic analysis to monitor lateral trunk motion as a potential compensation is recommended to deepen the data with which researchers can interpret their findings.

It is possible that the ability to anticipate a movement allows the body to plan a compensatory movement strategy to reduce high-risk motions in the lower extremity. Previous studies have shown that the ability to anticipate a cutting maneuver will alter kinematic performance both above and below the hip. This may have the effect of masking the influence of hip strength on lower extremity kinematics. There is also evidence that attending to a basketball, restricting the motion of 1 arm (as in holding a ball or stick), or even the presence of a static defensive opponent will increased the degree of knee valgus in test subjects. Any of these tools might be used by researchers to help elucidate the influence of hip strength on kinematics by reducing the body’s ability to compensate for weakness. It does, however, introduce the possible confounding interpretation of how much influence is due to hip strength versus neuromotor coordination and may also perpetuate the current problems with comparing studies due to task heterogeneity.

There is a need to develop a psychometrically verified instrument for assessing methodological quality in noninterventional studies such as those reviewed in this article. Finally, prospective studies assessing injury rates in subjects with weak hip abductors and external rotators would provide more clinically useful data on weakness as an injury risk.

Conclusion

There is a small amount of evidence that healthy subjects with weak hip abductors and perhaps weak external rotators demonstrate increased knee valgus. However, due to the variation in methodology and lack of agreement in the studies, it is not possible to make any definitive conclusions or clinical recommendations based on the results of this review. Further research is needed.
Acknowledgments

The author would like to thank David Soave for his help with statistical analysis, as well as Gerard Slobogean and Sue Stanton for their opinions and guidance with this review.

References


