ABSTRACT

**Background**: Anterior cruciate ligament (ACL) injury is common among females due to many anatomic, hormonal, and neuromuscular risk factors. One modifiable risk factor that places females at increased risk of ACL injury is a poor hamstrings: quadriceps (H:Q) co-activation ratio, which should be 0.6 or greater in order to decrease the stress placed on the ACL. Exercises that produce more quadriceps dominant muscle activation can add to the tension placed upon the ACL, potentially increasing the risk of ACL injury.

**Hypothesis/Purpose**: The purpose of this systematic review was to compare quadriceps and hamstring muscle activation during common closed kinetic chain therapeutic exercises in healthy female knees to determine what exercises are able to produce adequate H:Q co-activation ratios.

**Study Design**: Systematic Review

**Methods**: Multiple online databases were systematically searched and screened for inclusion. Eight articles were identified for inclusion. Data on mean electromyography (EMG) activation of both quadriceps and hamstring muscles, % maximal voluntary isometric contraction (MVIC), and H:Q co-activation ratios were extracted from the studies. Quality assessment was performed on all included studies.

**Results**: Exercises analyzed in the studies included variations of the double leg squat, variations of the single leg squat, lateral step-up, Fitter, Stairmaster® (Core Health and Fitness, Vancouver, WA), and slide board. All exercises, except the squat machine with posterior support at the level of the scapula and feet placed 50 cm in front of the hips, produced higher quadriceps muscle activation compared to hamstring muscle activation.

**Conclusion**: Overall, two leg squats demonstrate poor H:Q co-activation ratios. Single leg exercises, when performed between 30 and 90 degrees of knee flexion, produce adequate H:Q ratios, thereby potentially reducing the risk of tensile stress on the ACL and ACL injury.

**Level of Evidence**: 2a- Systematic Review of Cohort Studies

**Key words**: Anterior cruciate ligament, electromyography, hamstrings, quadriceps, resistance training

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28. maximal voluntary isometric contraction
29. maximum voluntary isometric contraction
30. 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29
31. resistance training[MeSH Terms]
32. resistance training[Text Word]
33. therapeutic exercise[Text Word]
34. muscle strengthening[Text Word]
35. exercise therapy[MeSH Terms]
36. exercise therapy[Text Word]
37. physical therapy[Text Word]
38. physiotherapy[Text Word]
39. exercise[MeSH Terms]
40. open chain kinetic exercise[Text Word]
41. closed chain kinetic exercise[Text Word]
42. 31 OR 32 OR 33 OR 34 OR 35 OR 36 OR 37 OR 38 OR 39 OR 40 OR 41
43. 5 AND 11 AND 30 AND 42

CINAHL Search Strategy
1. (MH “Hamstring Muscles”) OR “hamstrings” OR “hamstring” OR “hamstring muscle” OR “hamstrings muscle”
2. (MH “Quadriceps Muscles +”) OR “quadriceps” OR “quadricip” OR “quadricip muscle” OR “quadriceps muscle”
3. (MH “Electromyography”) OR “electromyography” OR “EMG” OR “muscle activation” OR “neuromuscular activation” OR “co-activation” OR “coactvation” OR “co-recruitment” OR “corecruitment” OR “co-contraction” OR “cocontraction” OR “h/q” OR “h/q ratio” OR “MVIC” OR “Maximal voluntary isometric contraction” OR “maximum voluntary isometric contraction”
4. (MH “Resistance Training”) OR “resistance training” OR (MH “Therapeutic Exercise”) OR “therapeutic exercise” OR (MH “Closed Kinetic Chain Exercises”) OR (MH “Lower Extremity Exercises”) OR (MH “Muscle Strengthening +”) OR “muscle strengthening” OR (MH “Open kinetic Chain Exercises”) OR “exercise therapy” OR (MH “Physical Therapy”) OR “Physical therapy” OR “physiotherapy” OR (MH “Exercise”) OR “closed kinetic chain” OR “closed chain” OR “open kinetic chain” OR “open chain”
5. 1 AND 2 AND 3 AND 4

Web of Science Search Strategy
1. TOPIC: (hamstrings) OR TOPIC: (hamstring) OR TOPIC: (hamstring muscle) OR TOPIC: (hamstrings muscle)
2. TOPIC: (quadriceps) OR TOPIC: (quadricep) OR TOPIC: (quadriceps muscle) OR TOPIC: (quadricep muscle)
3. TOPIC: (electromyography) OR TOPIC: (EMG) OR TOPIC: (muscle activation) OR TOPIC: (neuromuscular activation) OR TOPIC: (co-activation) OR TOPIC: (coactivation) OR TOPIC: (co-recruitment) OR TOPIC: (corecruitment) OR TOPIC: (co-contraction) OR TOPIC: (cocontraction) OR TOPIC: (h/q) OR TOPIC: (h/q ratio) OR TOPIC: (h/q activation) OR TOPIC: (h/q coactivation) OR TOPIC: (MVIC) OR TOPIC: (maximum voluntary isometric contraction) OR TOPIC: (maximal voluntary isometric contraction)
4. TOPIC: (resistance training) OR TOPIC: (therapeutic exercise) OR TOPIC: (muscle strengthening) OR TOPIC: (exercise therapy) OR TOPIC: (physical therapy) OR TOPIC: (physiotherapy) OR TOPIC: (exercise) OR TOPIC: (closed chain kinetic exercise) OR TOPIC: (open chain kinetic exercise)
5. 1 AND 2 AND 3 AND 4

Scopus Search Strategy
1. ( TITLE-ABS-KEY ( quadriceps* ) ) OR ( TITLE-ABS-KEY ( quadriceps femoris* ) ) OR ( TITLE-ABS-KEY ( quads* ) ) OR ( TITLE-ABS-KEY ( quad* ) ) OR ( TITLE-ABS-KEY ( quadricep* ) )
2. ( TITLE-ABS-KEY ( hamstrings* ) ) OR ( TITLE-ABS-KEY ( hamstring* ) )
3. ( TITLE-ABS-KEY ( resistance training ) ) OR TITLE-ABS-KEY ( open chain kinetic exercise) OR TITLE-ABS-KEY ( closed chain kinetic exercise ) OR TITLE-ABS-KEY ( therapeutic
exercise) OR TITLE-ABS-KEY (lower extremity exercise) OR TITLE-ABS-KEY (muscle strengthening) OR TITLE-ABS-KEY (neuromuscular facilitation) OR TITLE-ABS-KEY (plyometrics) OR TITLE-ABS-KEY (exercise therapy) OR TITLE-ABS-KEY (physical therapy) OR TITLE-ABS-KEY (physiotherapy) OR TITLE-ABS-KEY (neuromuscular activation))

4. ( (TITLE-ABS-KEY (electromyography) OR TITLE-ABS-KEY (emg) OR TITLE-ABS-KEY (electromyography feedback)))

5. 1 AND 2 AND 3 AND 4

**PEDro Search Strategy**

1. Knee EMG

**SportDiscus Search Strategy**

1. DE “QUADRICEPS muscle” OR DE “RECTUS femoris muscle” OR DE “VASTUS medialis”

2. DE “HAMSTRING muscle”

3. H/Q

4. H/Q ratio

5. H/Q activation

6. H/Q coactivation

7. DE “ELECTROMYOGRAPHY”

8. maximal voluntary isometric contraction

9. maximum voluntary isometric contraction

10. mvic

11. EMG

12. Muscle activation

13. Neuromuscular activation

14. Co-activation

15. Coactivation

16. Co-recruitment

17. Corecruitment

18. Co-contraction

19. Cocontraction

20. 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9 OR 10 OR 11 OR 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19


22. closed kinetic chain

23. closed chain

24. open kinetic chain exercises

25. open kinetic chain

26. open chain

27. therapeutic exercise

28. muscle strengthening

29. DE “PHYSICAL therapy”

30. Physical therapy

31. physiotherapy

32. 21 OR 22 OR 23 OR 24 OR 25 OR 26 OR 27 OR 28 OR 29 OR 30 OR 31

33. 1 AND 2 AND 20 AND 32