MMSx AUTHORITY · APPLIED BIOMECHANICS LAB

Hamstring and Thigh Rehabilitation

50 Evidence-Based Biomechanics Analyses

50 titles · four analysis slides each · movement analysis, verified research data, decision pathways and APA 7 references

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MMSx Authority Institute for Movement Mechanics & Biomechanics Research, Inc.

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BIOMECHANICS IS A FORCE-GOVERNED DECISION SYSTEM — NOT A POSTURE MODEL.

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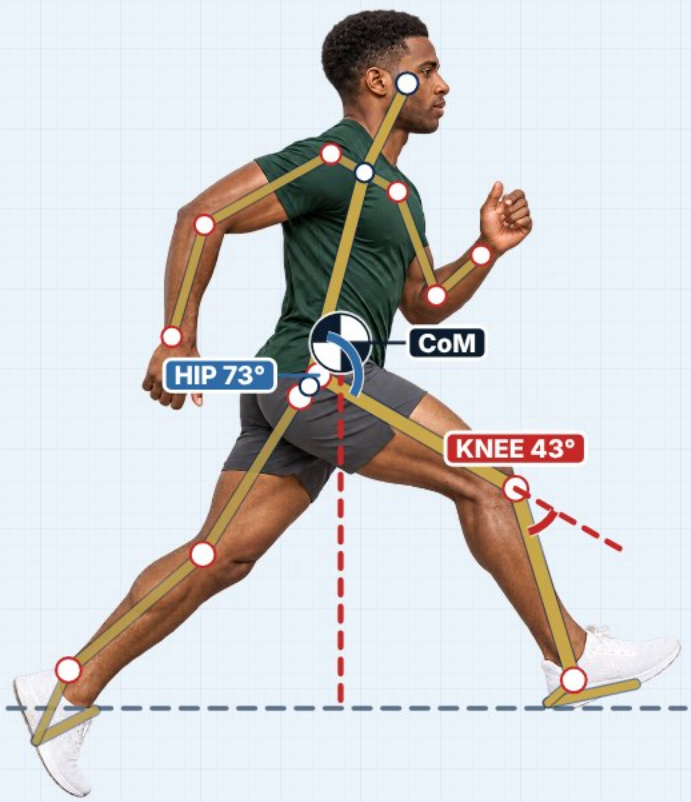
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HAMSTRING STRAIN: WHY IT IS THE MOST COMMON INJURY IN RUNNING SPORTS

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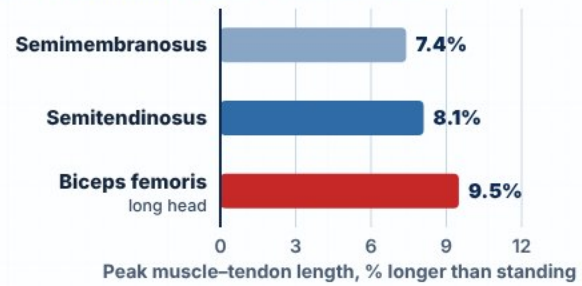
A · SPRINT LATE SWING, SIDE



Late swing stretches the hamstrings most

- Swing leg reaching forward with the hip flexed **73°** and the knee extending: the hamstrings are long and must brake the shank just before foot strike.
- In sprinting, peak hamstring length occurs in late swing, and biceps femoris long head is stretched furthest — the muscle injured most often.

Biceps femoris is stretched furthest



14 athletes sprinting at 80–100% of maximum speed; musculoskeletal model estimates. Thelen et al. (2005).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view; sprint poses are approximate. Educational, not diagnostic.

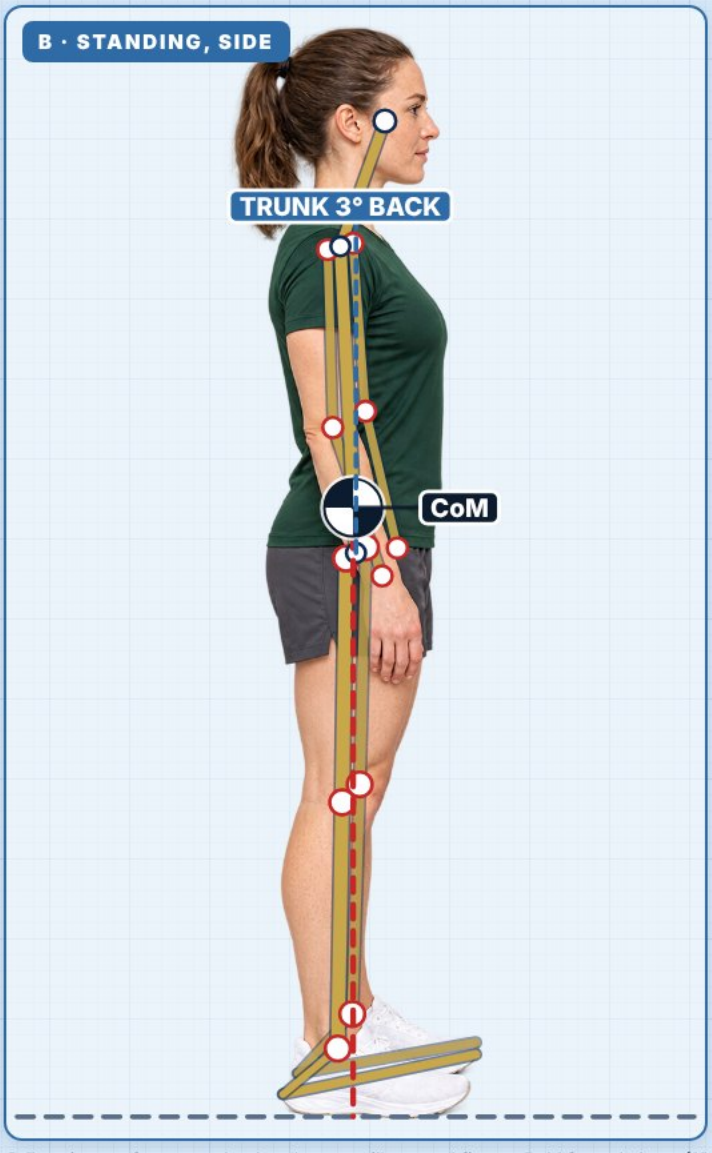
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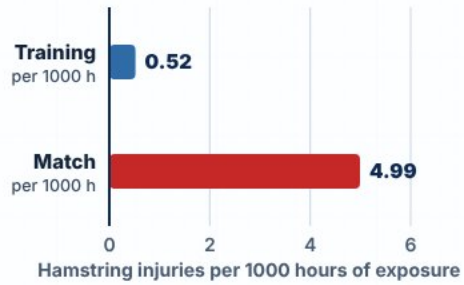
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Standing: the reference length

- Upright standing, trunk within **3°** of vertical: the hamstrings sit near their resting length, the baseline that sprinting lengths are compared against.
- In elite football, hamstring injuries rose from 12% to 24% of all injuries over 21 seasons, and two-thirds happened in matches.

Matches carry ten times the risk



3909 professional players, 2636 hamstring injuries; rate ratio 9.67 (95% CI 8.93–10.47). Ekstrand et al. (2023).

Key point: repeated maximal-speed running, often under fatigue, is where the risk concentrates.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line from hip to shoulder points in the side view. Educational, not diagnostic.

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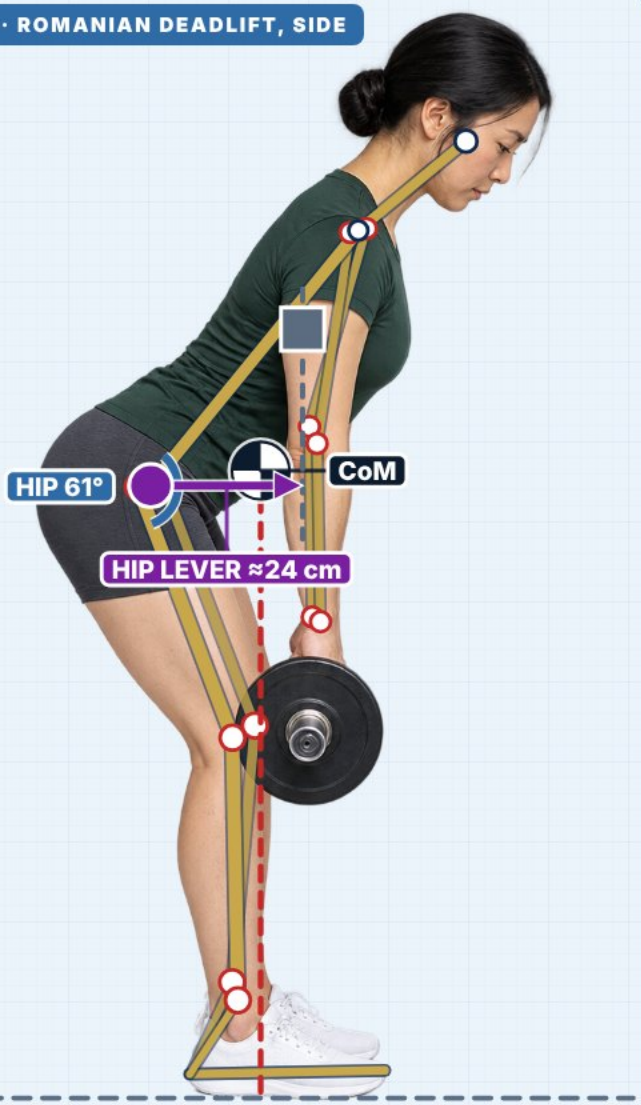
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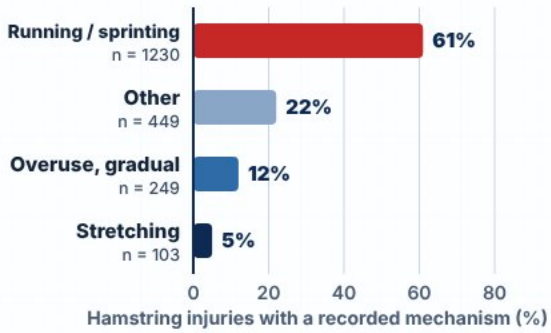
C · ROMANIAN DEADLIFT, SIDE



The hinge loads the hamstrings long

- Romanian deadlift with the hip flexed **61°**: the upper body acts **≈24 cm** in front of the hip, **≈97 N·m** before the bar, held by the hamstrings and glutes.
- Most injuries happen while running, not stretching, so strength in lengthened positions is a logical training target.

How hamstring injuries happen



2031 hamstring injuries with a recorded mechanism, UEFA Elite Club Injury Study. Ekstrand et al. (2023).

Myth: "Hamstring injuries come from not stretching." Only 5% occurred while stretching; 61% occurred while running.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Bar load not included. Educational, not diagnostic.

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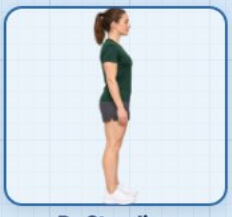
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A · Late swing
Hip 73°

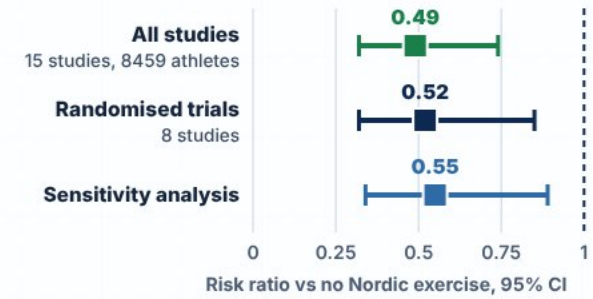


B · Standing
Reference length



C · Romanian deadlift
≈97 N·m

Eccentric work halves the risk



Programmes including the Nordic hamstring exercise vs not; injuries reduced by up to 51%. van Dyk et al. (2019).

Decision pathway

1. **PREVENT**
   Include eccentric hamstring work such as the Nordic exercise and build sprint exposure gradually.
2. **REHAB**
   After a strain, progress active loading in lengthened positions rather than resting.
3. **RETURN**
   Return to sprinting step by step; lengthened-position rehab returned footballers in 28 vs 51 days.

NOT RECOMMENDED

Relying on stretching alone for prevention; long periods of rest after a strain.

SEEK ASSESSMENT IF

A pop with large bruising high near the sitting bone, a slip into the splits, great difficulty walking, or numbness down the leg.

REFERENCES (APA 7)

Askling, C. M., Tengvar, M., & Thorstensson, A. (2013). Acute hamstring injuries in Swedish elite football: A prospective randomised controlled clinical trial comparing two rehabilitation protocols. *British Journal of Sports Medicine, 47*(15), 953–959. https://doi.org/10.1136/bjsports-2013-092165

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Ekstrand, J., Bengtsson, H., Waldén, M., Davison, M., Khan, K. M., & Hägglund, M. (2023). Hamstring injury rates have increased during recent seasons and now constitute 24% of all injuries in men's professional football: The UEFA Elite Club Injury Study from 2001/02 to 2021/22. *British Journal of Sports Medicine, 57*(5), 292–298. https://doi.org/10.1136/bjsports-2021-105407

Thelen, D. G., Chumanov, E. S., Hoerth, D. M., Best, T. M., Swanson, S. C., Li, L., Young, M., & Heiderscheit, B. C. (2005). Hamstring muscle kinematics during treadmill sprinting. *Medicine and Science in Sports and Exercise, 37*(1), 108–114. https://doi.org/10.1249/01.MSS.0000150078.79120.C8

van Dyk, N., Behan, F. P., & Whiteley, R. (2019). Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: A systematic review and meta-analysis of 8459 athletes. *British Journal of Sports Medicine, 53*(21), 1362–1370. https://doi.org/10.1136/bjsports-2018-100045

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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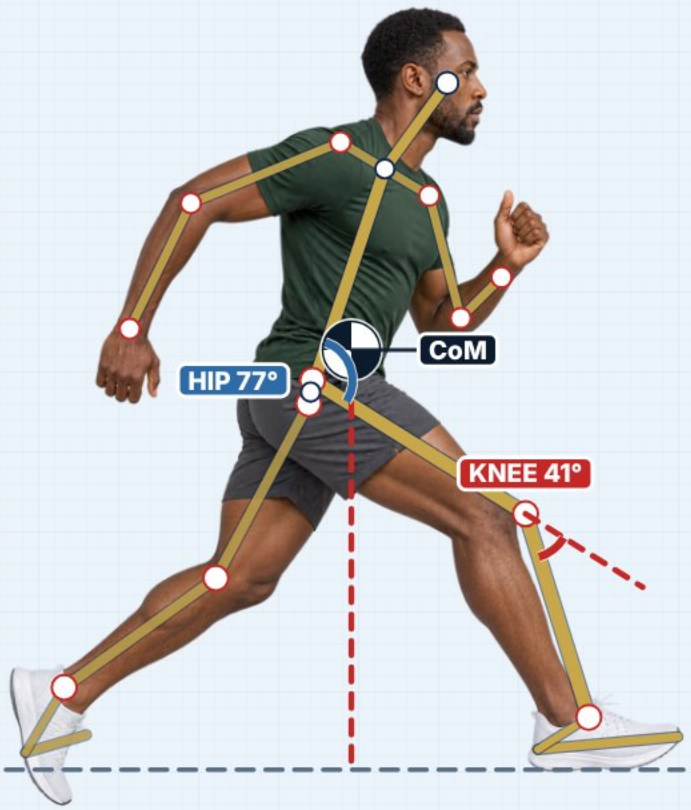
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HAMSTRING PAIN WHEN SPRINTING: WHAT HAPPENS IN THE LATE SWING PHASE

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A · SPRINT LATE SWING, SIDE



Late swing: braking a fast shank

- Front leg reaching forward with the hip flexed **77°** and the knee only **41°** bent: the hamstrings are long and active as they slow the shank before foot strike.
- In a sprint model, biceps femoris and semimembranosus forces peaked at about 85–95% of the stride, while the muscles were lengthening, and exceeded their stance peaks.

Swing peaks exceed stance peaks



12 runners at 100% of maximum speed; forward-dynamic simulation (model estimates). Chumanov et al. (2011).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view; sprint poses are approximate. Educational, not diagnostic.

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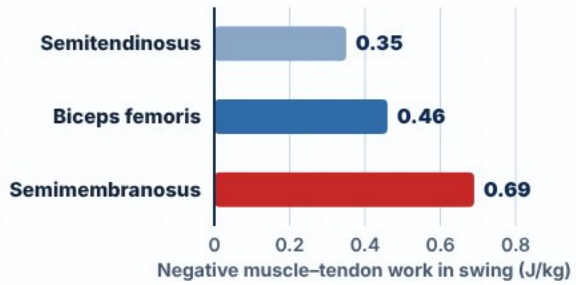
B · SPRINT FOOT STRIKE, SIDE



Foot strike: the braking job just ended

- Front foot meeting the ground ahead of the hips with the knee bent **29°**, the rear leg trailing behind: the swing-phase lengthening work is complete and stance loading begins.
- From 50% to 90% of the stride the hamstrings lengthened under load, and the energy they absorbed rose significantly with running speed.

Energy each hamstring absorbs



12 runners at 100% of maximum speed; model estimates. Chumanov et al. (2011).

Myth: "Hamstrings tear when the foot hits the ground." Peak length occurs in late swing; early stance also loads the muscle, but late swing is the key lengthening load.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle from pose landmarks in the side view; sprint poses are approximate. Educational, not diagnostic.

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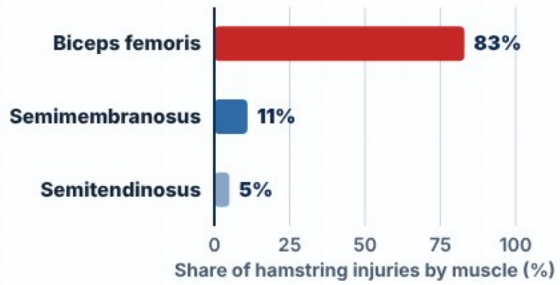
C · HIGH-KNEE MARCH, SIDE



The march: hip flexed, knee bent

- Right thigh lifted with the hip flexed **93°** and the knee bent **94°**: the bent knee slackens the hamstrings, so this drill never reaches the long late-swing position.
- Biceps femoris, the muscle stretched furthest in late swing, accounted for 83% of hamstring injuries in professional football.

Biceps femoris is injured most



516 hamstring injuries in professional football players. Ekstrand et al. (2012).

Key point: drills rehearse rhythm and posture; strength in long positions has to be built separately.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles of the lifted (right) leg from pose landmarks in the side view. Educational, not diagnostic.

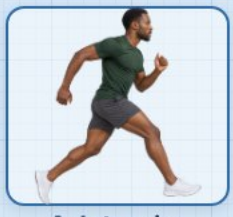
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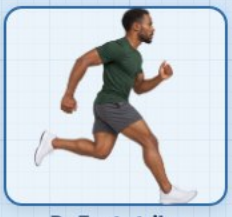
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A · Late swing
Hip 77°, knee 41°

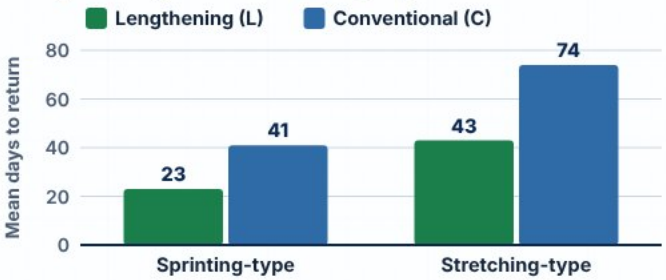


B · Foot strike
Knee 29°



C · High-knee march
Hip 93°, knee 94°

Lengthening rehab returns players sooner



75 elite footballers, MRI-verified injury, randomised to L- or C-protocol. Askling et al. (2013).

Decision pathway

1. **RECOGNISE**
   Sudden posterior-thigh pain late in the stride, as the leg reaches forward, fits a sprinting-type strain.
2. **LOAD LONG**
   Rehab and prevention should include eccentric, high-load work at long hamstring lengths.
3. **RE-EXPOSE**
   Rebuild sprint speed step by step, because late-swing demand rises with speed.

NOT RECOMMENDED

Sprinting through sudden posterior-thigh pain; relying on drills alone to restore long-length strength.

SEEK ASSESSMENT IF

Pain that makes walking difficult, visible bruising, a palpable gap, or a pop high near the sitting bone.

REFERENCES (APA 7)

Askling, C. M., Tengvar, M., & Thorstensson, A. (2013). Acute hamstring injuries in Swedish elite football: A prospective randomised controlled clinical trial comparing two rehabilitation protocols. *British Journal of Sports Medicine, 47*(15), 953–959. https://doi.org/10.1136/bjsports-2013-092165

Chumanov, E. S., Heiderscheit, B. C., & Thelen, D. G. (2011). Hamstring musculotendon dynamics during stance and swing phases of high-speed running. *Medicine and Science in Sports and Exercise, 43*(3), 525–532. https://doi.org/10.1249/MSS.0b013e3181f23fe8

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Ekstrand, J., Healy, J. C., Waldén, M., Lee, J. C., English, B., & Hägglund, M. (2012). Hamstring muscle injuries in professional football: The correlation of MRI findings with return to play. *British Journal of Sports Medicine, 46*(2), 112–117.

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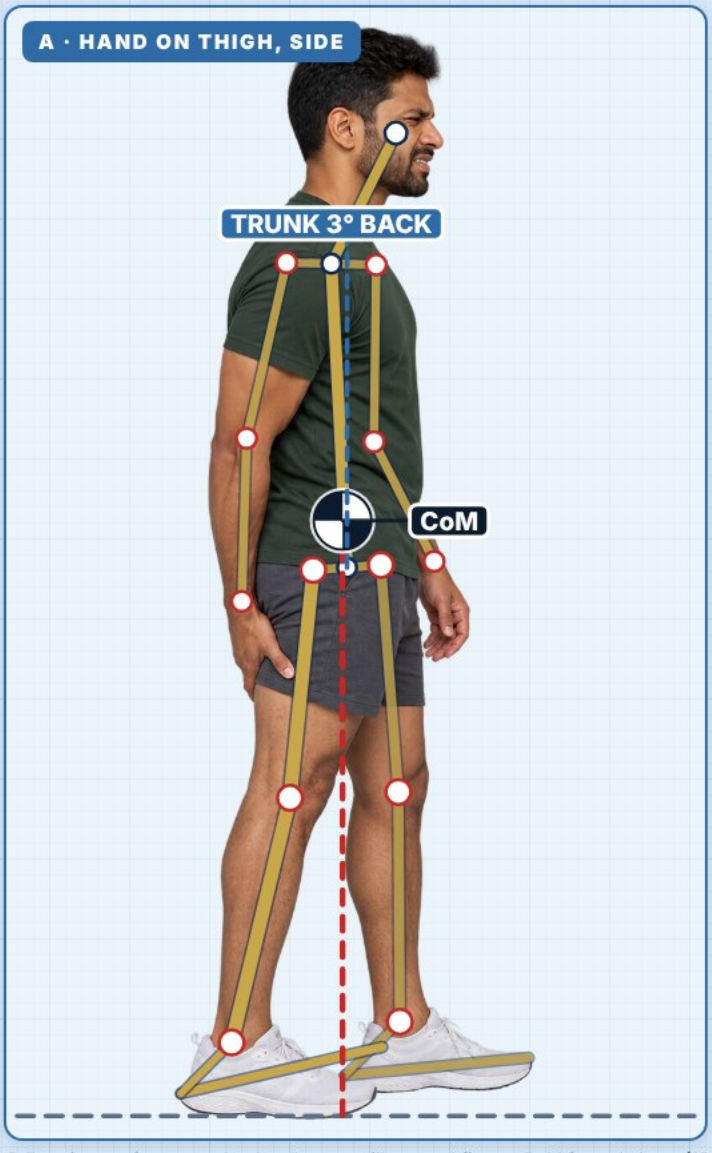
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PULLED HAMSTRING: GRADE 1, 2 OR 3, AND WHAT EACH MEANS FOR RECOVERY

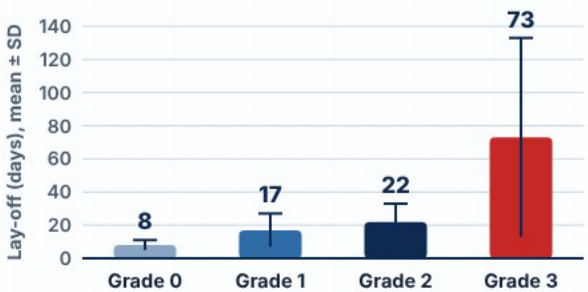
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Grade describes the damage, not the pain

- Standing with a hand on the back of the right thigh and a wince, trunk within **3°** of vertical: how it feels on day one does not reveal the grade.
- On MRI, grade 0 shows no visible injury, grade 1 oedema without fibre disruption, grade 2 a partial tear and grade 3 a complete muscle or tendon rupture.

Higher grade, longer lay-off



516 hamstring injuries in professional football; grades differed ($p < 0.0001$); grade 3 n = 6. Ekstrand et al. (2012).

Myth: "A grade 1 strain is trivial." Grades 0–1 were 70% of injuries and caused 56% of all lay-off days.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line from hip to shoulder points in the side view. Educational, not diagnostic.

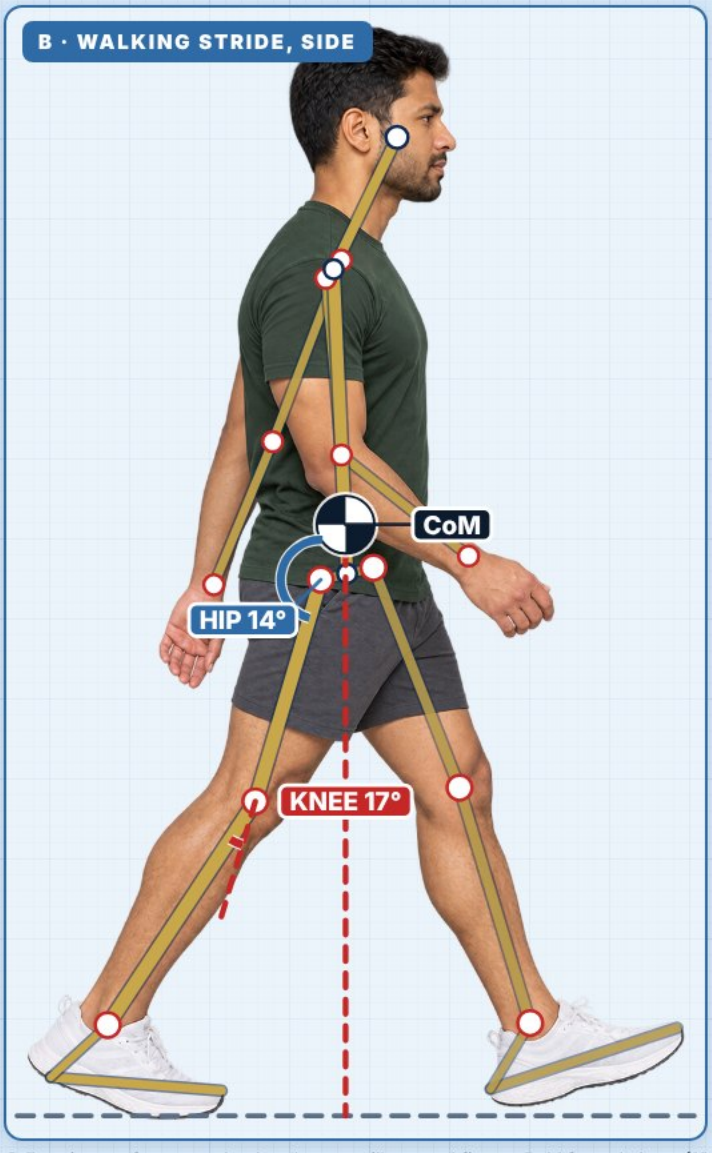
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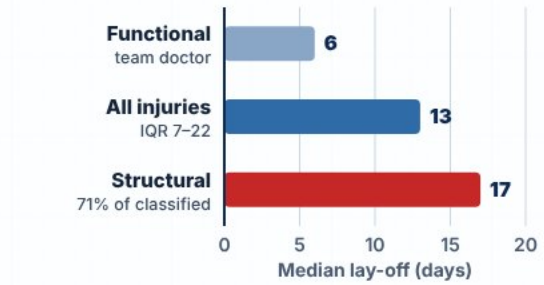


2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip angle from pose landmarks in the side view; walking poses are approximate. Educational, not diagnostic.

Walking is an early checkpoint

- Normal stride with the front heel landing and the hip flexed about **14°**: walking needs little hamstring length, so a pain-free, even stride is an early milestone rather than proof of healing.
- Structural injuries, which made up 71% of classified cases, kept players out nearly three times longer than functional ones.

Structural injuries take longer



UEFA Elite Club Injury Study; category assigned by the team doctor. Ekstrand et al. (2023).

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PULLED HAMSTRING: GRADE 1, 2 OR 3, AND WHAT EACH MEANS FOR RECOVERY

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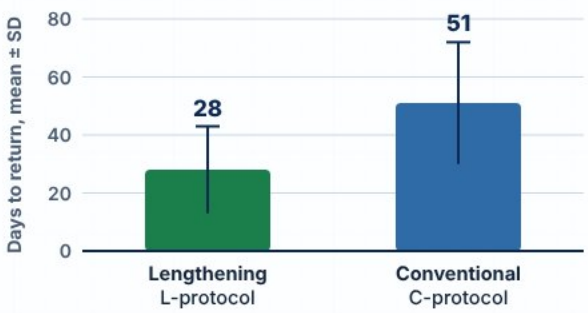
C · HEEL-DIG BRIDGE, SIDE



Early loading, low length

- Lying bridge with the heels dug in, knees bent about **106°** and shoulders, hips and knees in line: an isometric hamstring effort at short length, a typical early-stage start.
- Grade predicts the likely range; the rehabilitation plan shifts where in that range the athlete lands.

The rehab plan changes the timeline



75 elite footballers with MRI-verified acute injury, randomised; ranges 8–58 vs 12–94 days. Askling et al. (2013).

Key point: progress from short-length isometrics towards loading in lengthened positions as symptoms allow.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Lying pose: knee angle approximate; hip angle not reported. Educational, not diagnostic.

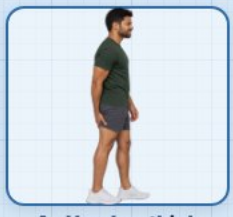
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A · Hand on thigh
Grade not visible

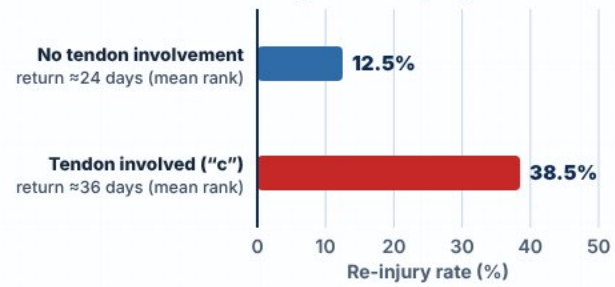


B · Walking
Early milestone



C · Heel-dig bridge
Knee ≈106°, isometric

Tendon involvement triples re-injury



Elite footballers graded with the British Athletics classification; p = 0.031 re-injury, p = 0.013 return. Shamji et al. (2021).

Decision pathway

1. **GRADE AND SITE**
   Use the grade and whether the tendon is involved to estimate the likely range, not a fixed date.
2. **LOAD EARLY**
   Start with pain-guided isometrics, then progress to lengthened-position loading.
3. **REVIEW**
   Imaging helps most when tendon involvement or a high-grade tear is suspected.

NOT RECOMMENDED

Treating a "mild" grade as trivial; setting the return date from the grade number alone.

SEEK ASSESSMENT IF

A pop with inability to continue, marked bruising, a palpable gap, pain high near the sitting bone, or no improvement in walking within days.

REFERENCES (APA 7)

Askling, C. M., Tengvar, M., & Thorstensson, A. (2013). Acute hamstring injuries in Swedish elite football: A prospective randomised controlled clinical trial comparing two rehabilitation protocols. *British Journal of Sports Medicine, 47*(15), 953–959. https://doi.org/10.1136/bjsports-2013-092165

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Ekstrand, J., Bengtsson, H., Waldén, M., Davison, M., Khan, K. M., & Hägglund, M. (2023). Hamstring injury rates have increased during recent seasons and now constitute 24% of all injuries in men's professional football: The UEFA Elite Club Injury Study from 2001/02 to 2021/22. *British Journal of Sports Medicine, 57*(5), 292–298. https://doi.org/10.1136/bjsports-2021-105407

Ekstrand, J., Healy, J. C., Waldén, M., Lee, J. C., English, B., & Hägglund, M. (2012). Hamstring muscle injuries in professional football: The correlation of MRI findings with return to play. *British Journal of Sports Medicine, 46*(2), 112–117.

Shamji, R., James, S. L. J., Botchu, R., Khurniawan, K. A., Bhogal, G., & Rushton, A. (2021). Association of the British Athletic Muscle Injury Classification and anatomic location with return to full training and reinjury following hamstring injury in elite football. *BMJ Open Sport & Exercise Medicine, 7*(2), e001010. https://doi.org/10.1136/bmjsem-2020-001010

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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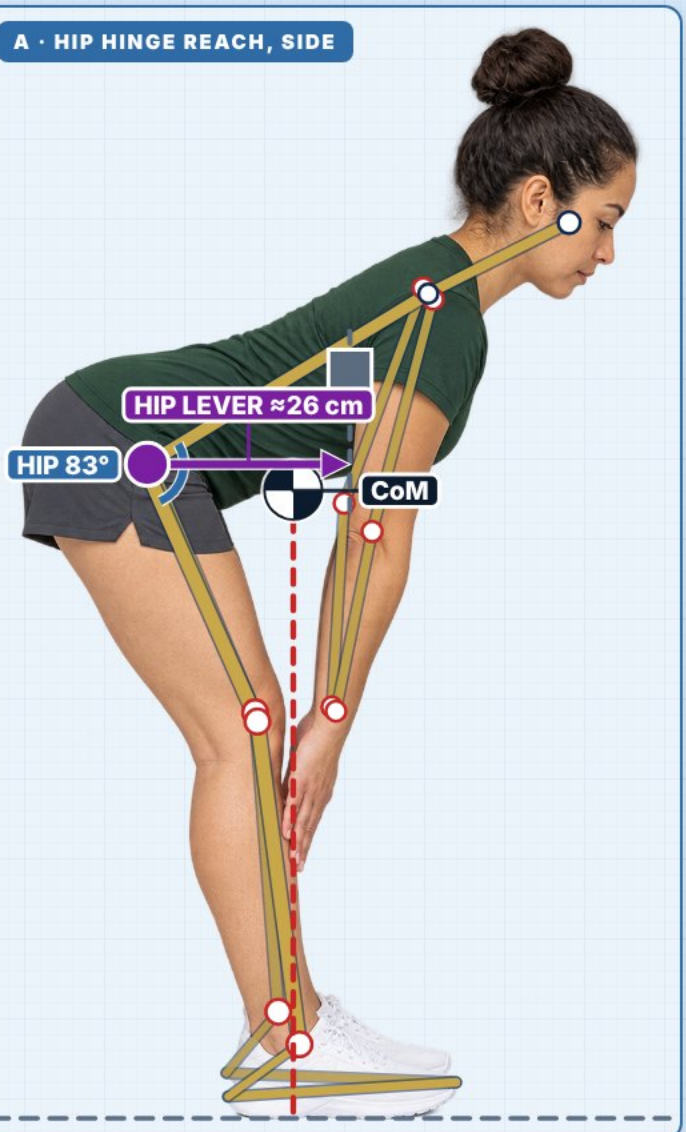
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HAMSTRING TEAR: WHEN A TENDON INJURY NEEDS A SURGICAL OPINION

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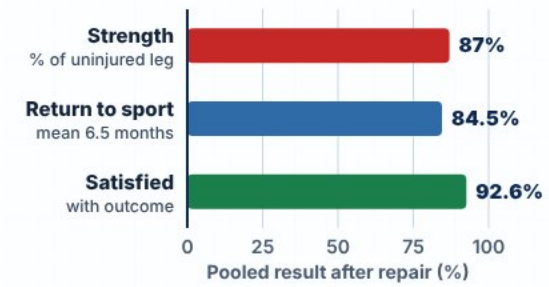
A · HIP HINGE REACH, SIDE



The hinge: a late-stage target

- Forward bend with the hip flexed **83°** and knees nearly straight: hip lever **≈26 cm**, hip moment **≈104 N·m**, carried by the hamstrings at their origin on the sitting bone.
- A proximal avulsion pulls the tendons off that bone, usually in a forced hip-flexion, knee-extension stretch such as a slip.

After repair: good, but not full strength



Meta-analysis, 35 studies, 1530 surgically repaired proximal hamstrings. Hillier-Smith & Paton (2022).

Key point: strength averaged 87% of the other leg, so long-term loading of the hinge still matters after surgery.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Educational, not diagnostic.

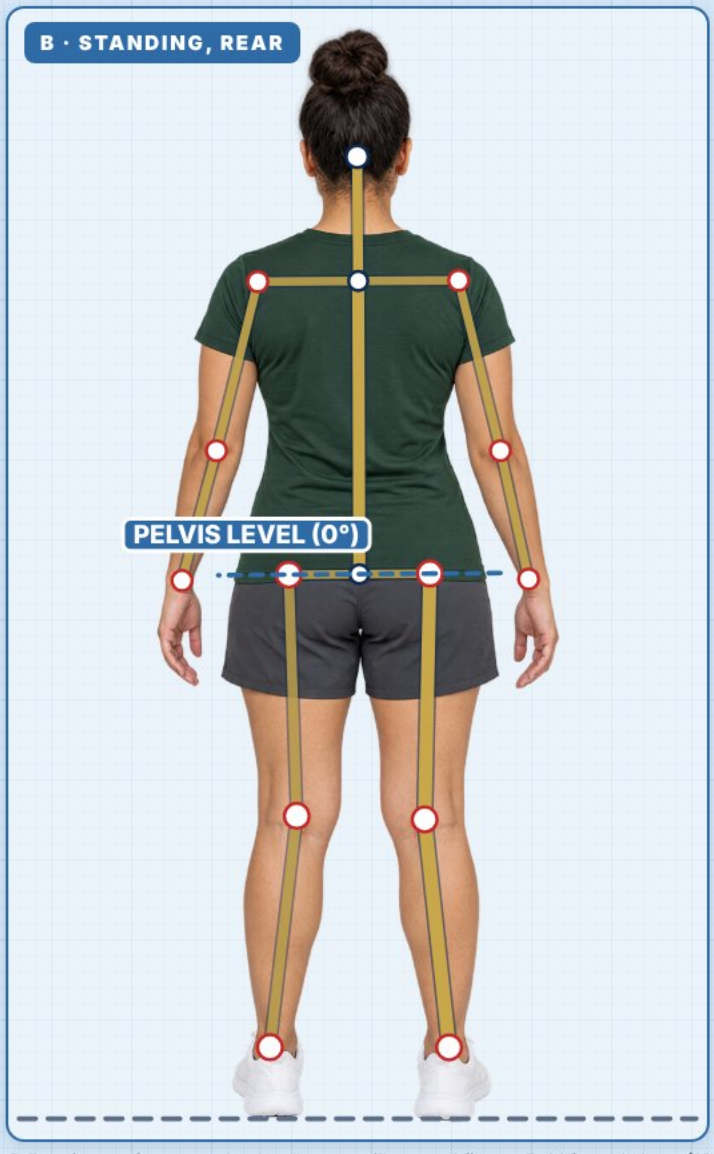
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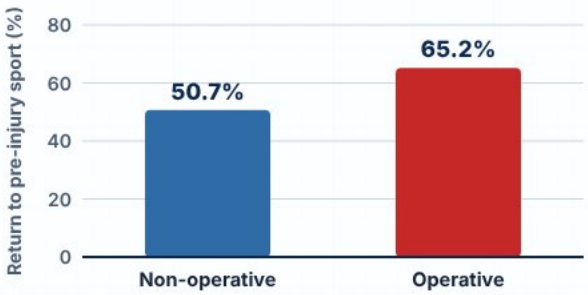
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What the rear view can show

- Standing from behind with the pelvis level (**0°**): after an avulsion, marked bruising in the buttock or back of the thigh and a gap below the sitting bone are typical signs.
- Surgery was linked with higher return to pre-injury sport (odds ratio 1.83), but patient-reported function scores did not differ significantly.

Surgery vs non-operative care



Meta-analysis of seven comparative studies (eight cohorts), proximal avulsions; p = 0.005. Thamrongskulsiri et al. (2025).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Pelvis line between the hip points in the rear view. Educational, not diagnostic.

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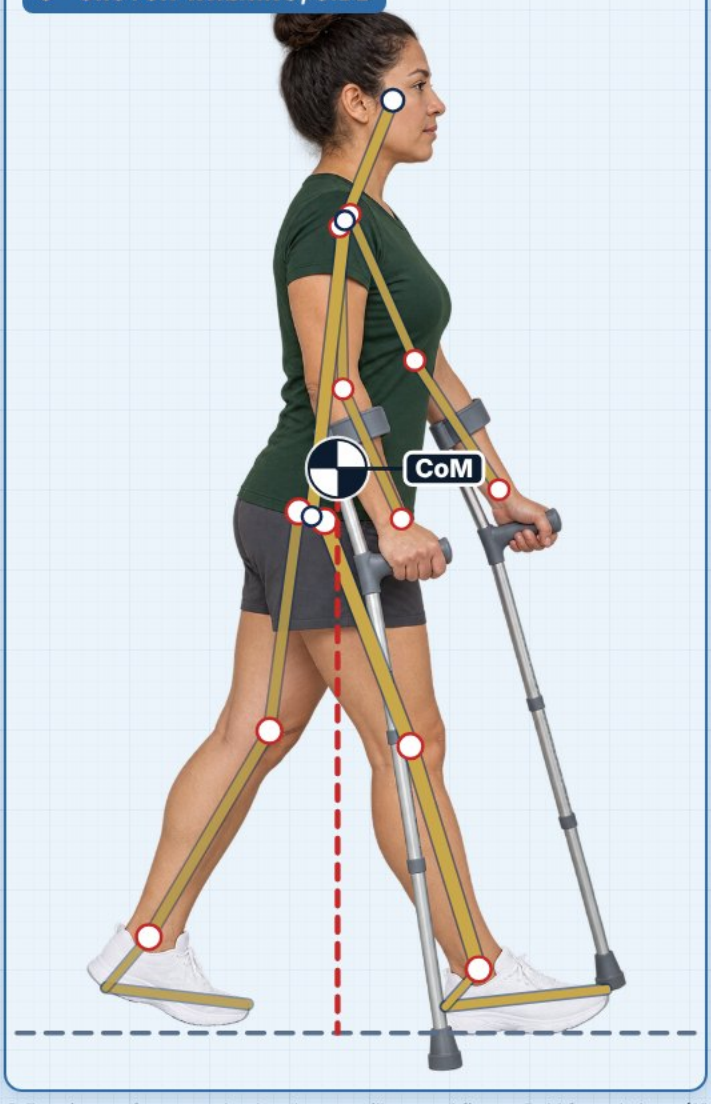
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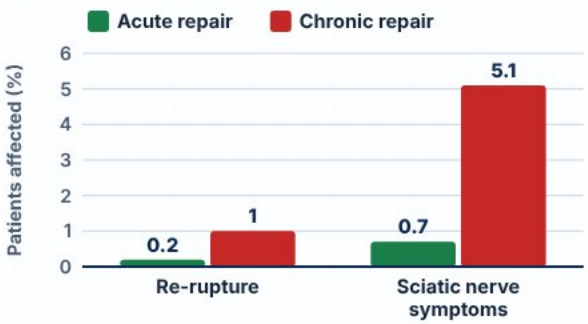
C · CRUTCH WALKING, SIDE



Delay changes the risks

- Walking slowly with two elbow crutches, the right foot only lightly touching: marked difficulty walking after a hamstring injury is a reason for prompt specialist review.
- Return to sport was similar after acute and chronic repair (88.2% vs 87.3%), but delayed repair carried more nerve symptoms and re-ruptures.

Early repair: fewer complications



1530 repairs; re-rupture p = 0.045, sciatic symptoms p < 0.001. Hillier-Smith & Paton (2022).

Myth: "All hamstring tears heal with rest." Most muscle strains do; a retracted tendon avulsion is a different injury.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Crutch walking: joint angles not reported. Educational, not diagnostic.

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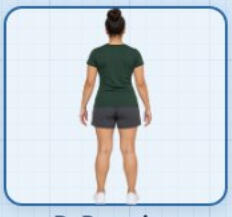
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A · Hip hinge
≈104 N·m at the hip

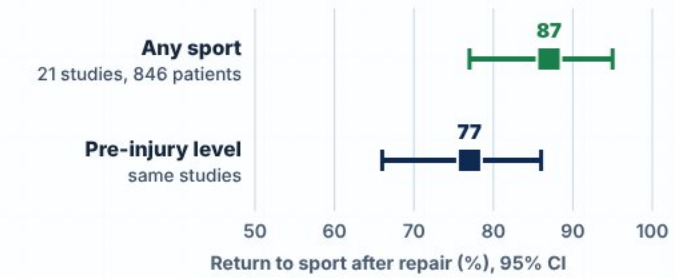


B · Rear view
Look for bruising



C · Crutch walking
Prompt review

Most return to sport after repair



Meta-analysis; mean return 5.8 months (range 1–36), mean age 41.4 years. Coughlin et al. (2020).

Decision pathway

1. **RECOGNISE**
   Forced stretch, rapid severe pain and bruising high in the thigh suggest a tendon avulsion.
2. **REFER EARLY**
   An expert review advocates surgery for two-tendon tears retracted >2 cm and all three-tendon tears, ideally within 4 weeks.
3. **DECIDE TOGETHER**
   Smaller tears with little retraction are often managed without surgery, guided by goals.

NOT RECOMMENDED

Waiting weeks to "see if it settles" after a forced-stretch injury with heavy bruising.

SEEK ASSESSMENT IF

Rapid severe pain with bruising in the buttock or thigh, a gap below the sitting bone, marked difficulty walking, or sciatica-like symptoms.

REFERENCES (APA 7)

Atwal, N., Wood, D., & Kuah, D. (2019). Surgical management of proximal hamstring rupture. Aspetar Sports Medicine Journal. https://journal.aspetar.com/viewarticle.aspx?id=441

Coughlin, R. P., Kay, J., Shanmugaraj, A., Memon, M., Naji, L., & Ayeni, O. R. (2020). Return to sport after surgical management of proximal hamstring avulsions: A systematic review and meta-analysis. *Clinical Journal of Sport Medicine, 30*(6), 598–611. https://doi.org/10.1097/JSM.0000000000000688

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Hillier-Smith, R., & Paton, B. (2022). Outcomes following surgical management of proximal hamstring tendon avulsions: A systematic review and meta-analysis. *Bone & Joint Open, 3*(5), 415–422. https://doi.org/10.1302/2633-1462.35.BJO-2021-0196.R1

Thamrongskulsiri, N., Limskul, D., Tanpowpong, T., Kuptniratsaikul, S., Ranawat, A. S., & Itthipanichpong, T. (2025). No difference in patient-reported outcomes between operative and non-operative management of proximal hamstring injuries, but return to sports is higher in operative treatment: A systematic review and meta-analysis. *Journal of Experimental Orthopaedics, 12*(3), e70327. https://doi.org/10.1002/jeo2.70327

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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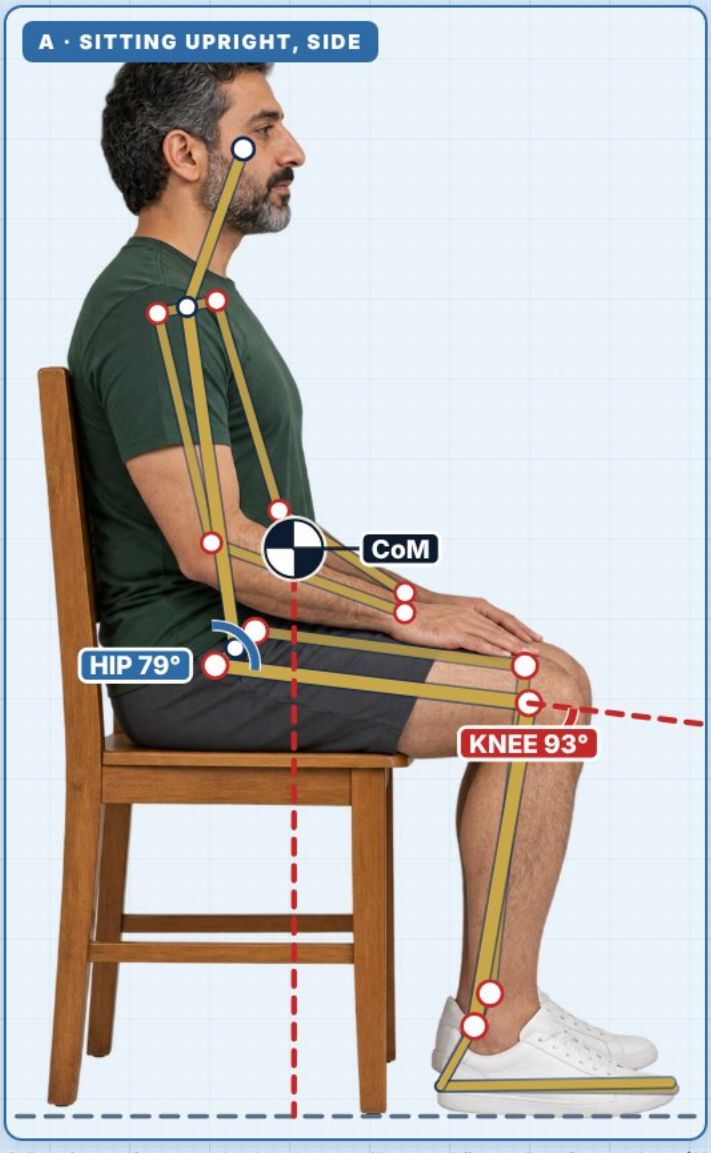
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PROXIMAL HAMSTRING TENDINOPATHY: PAIN AT THE SITTING BONE

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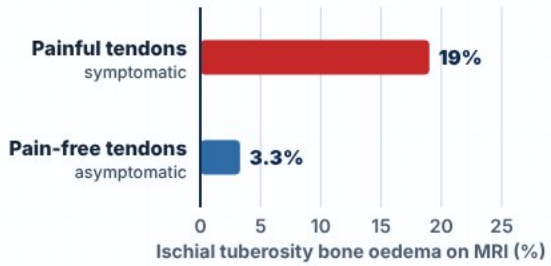
A · SITTING UPRIGHT, SIDE



Sitting presses the tendon on the bone

- Upright on a hard wooden chair, hip flexed **79°** and knee **93°**: body weight rests on the sitting bones, where the common hamstring tendon attaches.
- Proximal hamstring tendinopathy is a load-related, often long-standing pain deep in the buttock at that origin; sitting is a typical trigger.

Bone oedema is more common in pain



MRI of 118 patients, 21 with unilateral tendinopathy. De Smet et al. (2012), as summarised by Reurink & van der Made (2019).

Myth: "The scan shows a damaged tendon, so that is the problem." Over 90% of tendons showed raised signal, unrelated to symptoms.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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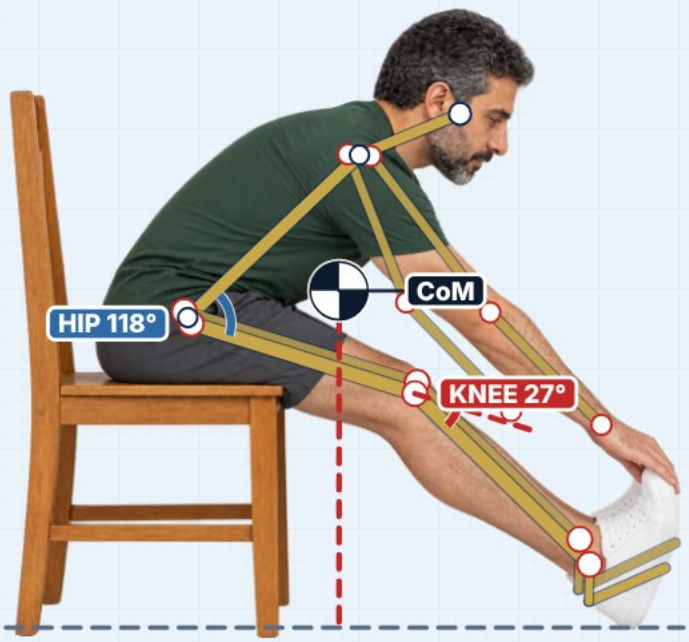
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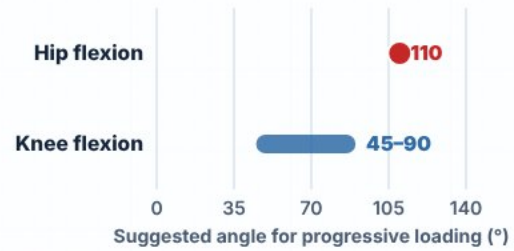
B · SEATED FORWARD REACH, SIDE



Deep flexion, straight knee: most provocative

- Seated, trunk folded over straight legs: hip flexed **118°** with the knee bent only **27°**, combining compression at the sitting bone with tendon stretch.
- A review suggests loading around 110° of hip flexion with the knee bent 45–90°, reached gradually; this straight-knee position goes beyond that early on.

Where to load the tendon



Systematic review of 13 studies; recommended ranges, not measured data. Dizon et al. (2023).

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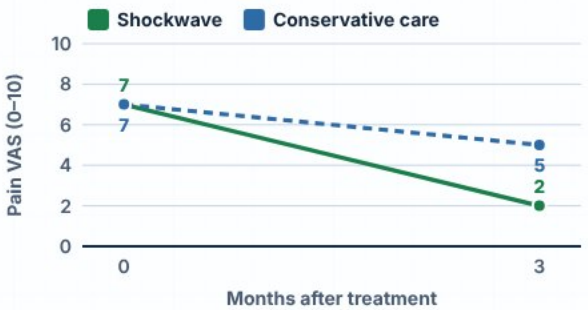
C · LONG-LEVER BRIDGE, SIDE



Start with low compression

- Lying with the heels on a low step, legs nearly straight and hips lifted a few centimetres: the hamstrings work isometrically with the hip near neutral, away from compressive flexion.
- In one trial, shockwave therapy cut pain more than conservative care at 3 months; a later review places it as an adjunct to loading.

Pain before and 3 months after



40 professional athletes, randomised (n = 20 each); ≥50% pain relief in 85% vs 10%; $p < 0.001$. Cacchio et al. (2011).

Key point: progressive loading is the core of care; compressive hip flexion is reintroduced gradually.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Lying pose: skeleton only; joint angles not reported. Educational, not diagnostic.

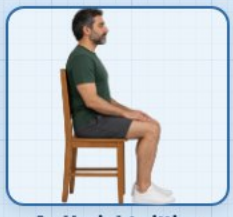
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A · Upright sitting
Hip 79°

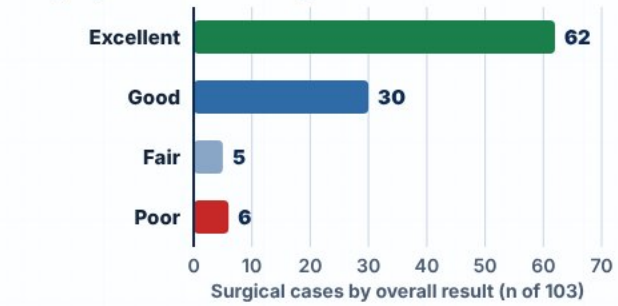


B · Seated reach
Hip 118°, knee 27°



C · Long-lever bridge
Hip near neutral

Surgery is for refractory cases



Case series of athletes, 103 cases in 90 patients; 80 of 90 returned to the same level after a mean 5 months. Lempainen et al. (2009).

Decision pathway

1. **LOAD**
   Begin with low-compression isometrics and progress tendon load over weeks; short cuts are counterproductive.
2. **MODIFY**
   Reduce long sitting on hard surfaces and deep hip flexion while the tendon is irritable.
3. **ESCALATE**
   Consider shockwave as an adjunct, and surgery only after conservative care fails.

NOT RECOMMENDED

Aggressive hamstring stretching into deep hip flexion during the irritable phase.

SEEK ASSESSMENT IF

Pain after a sudden injury with bruising, leg numbness, pins and needles or weakness, or night pain, fever or unexplained weight loss.

REFERENCES (APA 7)

Cacchio, A., Rompe, J. D., Furia, J. P., Susi, P., Santilli, V., & De Paulis, F. (2011). Shockwave therapy for the treatment of chronic proximal hamstring tendinopathy in professional athletes. *The American Journal of Sports Medicine, 39*(1), 146–153. https://doi.org/10.1177/0363546510379324

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

De Smet, A. A., Blankenbaker, D. G., Alsheik, N. H., & Lindstrom, M. J. (2012). MRI appearance of the proximal hamstring tendons in patients with and without symptomatic proximal hamstring tendinopathy. *AJR American Journal of Roentgenology, 198*(2), 418–422.

Dizon, P., Jeanfavre, M., Leff, G., & Norton, R. (2023). Comparison of conservative interventions for proximal hamstring tendinopathy: A systematic review and recommendations for rehabilitation. *Sports, 11*(3), 53. https://doi.org/10.3390/sports11030053

Lempainen, L., Sarimo, J., Mattila, K., Vaittinen, S., & Orava, S. (2009). Proximal hamstring tendinopathy: Results of surgical management and histopathologic findings. *The American Journal of Sports Medicine, 37*(4), 727–734. https://doi.org/10.1177/0363546508330129

Reurink, G., & van der Made, A. D. (2019). Managing the athlete with a stubborn proximal hamstring tendinopathy. Aspetar Sports Medicine Journal, 8. https://journal.aspetar.com/en/journals/volume-8-targeted-topic-sports-medicine-and-science-in-athletics/managing-the-athlete-with-a-stubborn-proximal-hamstring-tendinopathy

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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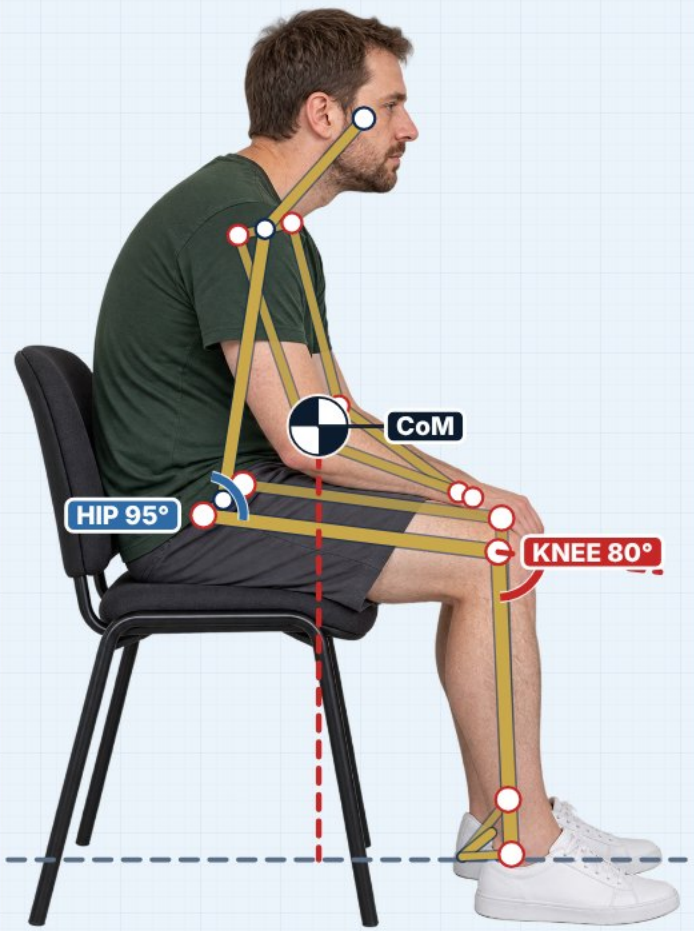
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PAIN WHEN SITTING: WHEN THE HAMSTRING TENDON IS THE SOURCE

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A · SLUMPED SITTING, SIDE



Slumped sitting loads the sitting bone

- Rounded back on a plain chair, hip flexed **95°** and knee **80°**: the pelvis rolls back and weight rests on the ischial tuberosities, pressing the tendon against the bone.
- Local pain in sitting and driving is typical of proximal hamstring tendinopathy (Reurink & van der Made, 2019), but lumbar, sacroiliac and nerve sources must also be considered.

Pain-provocation tests are reliable



92 athletes, 46 with and 46 without chronic tendinopathy. Cacchio et al. (2012).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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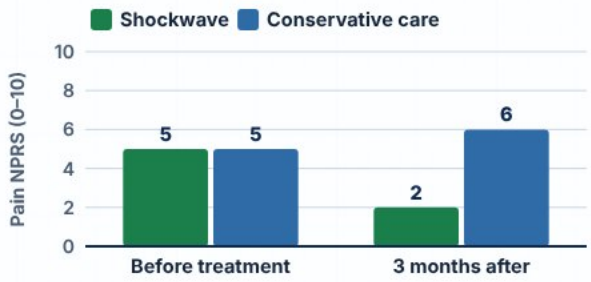
B · DRIVING POSITION, SIDE



Driving adds stretch to compression

- Car seat with the right leg reaching forward, hip flexed **79°** and knee bent only **55°**: a straighter knee lengthens the hamstrings while the tendon is pressed on the seat.
- In athletes with chronic tendinopathy, pain fell with shockwave therapy at 3 months but not with traditional conservative care.

Pain scores with treatment



40 professional athletes, randomised (n = 20 each); $p < 0.001$ at 3 months. Cacchio et al. (2011).

Myth: "Sitting pain means I must stretch my hamstrings more." Deep stretching adds hip-flexion compression and is usually provocative early.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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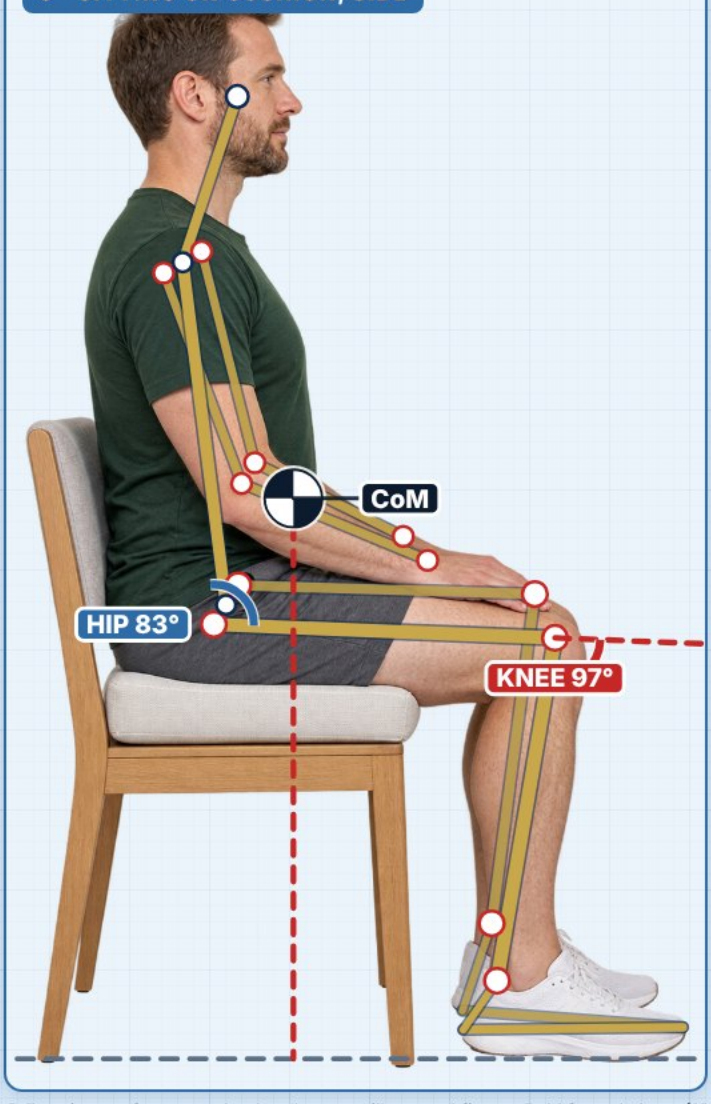
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PAIN WHEN SITTING: WHEN THE HAMSTRING TENDON IS THE SOURCE

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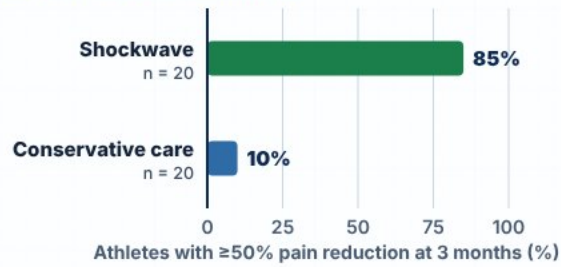
C · SITTING ON CUSHION, SIDE



Change the seat, keep loading

- Upright on a firm cushion under the thighs, hip **83°** and knee **97°**: sharing weight onto the thighs is a practical way to ease sitting-bone pressure (clinical rationale, not measured).
- Shockwave is an adjunct; progressive tendon loading remains the foundation of care.

Responders to treatment



Same randomised trial in professional athletes; single trial. Cacchio et al. (2011).

Key point: reduce compression while the tendon is irritable, then reintroduce sitting and hip flexion gradually.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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A · Slumped
Hip 95°

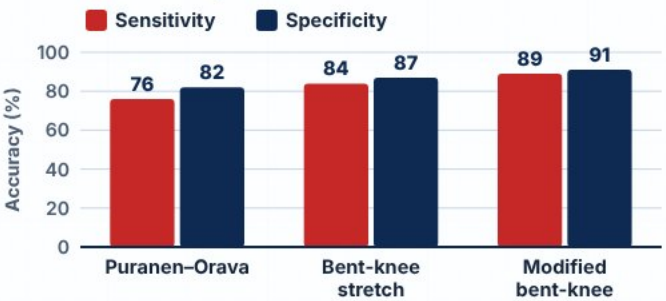


B · Driving
Knee 55°



C · Cushion
Pressure shared

Which test best points to the tendon?



92 athletes. Cacchio et al. (2012); accuracy values via a secondary summary of that study.

Decision pathway

1. **TEST**
   Typical sitting pain plus a positive modified bent-knee stretch test makes a tendon source more likely.
2. **MODIFY**
   Use firmer cushions, breaks from sitting and less slumping while the tendon settles.
3. **LOAD**
   Progress tendon loading over weeks; consider shockwave only as an adjunct.

NOT RECOMMENDED

Stretching harder into deep hip flexion to relieve sitting pain.

SEEK ASSESSMENT IF

Pins and needles, numbness or weakness in the leg, saddle numbness or bladder or bowel change (urgent), fever, night pain, or bruising after sudden injury.

REFERENCES (APA 7)

Cacchio, A., Borra, F., Severini, G., Foglia, A., Musarra, F., Taddio, N., & De Paulis, F. (2012). Reliability and validity of three pain provocation tests used for the diagnosis of chronic proximal hamstring tendinopathy. *British Journal of Sports Medicine, 46*(12), 883–887. https://doi.org/10.1136/bjsports-2011-090325

Cacchio, A., Rompe, J. D., Furia, J. P., Susi, P., Santilli, V., & De Paulis, F. (2011). Shockwave therapy for the treatment of chronic proximal hamstring tendinopathy in professional athletes. *The American Journal of Sports Medicine, 39*(1), 146–153. https://doi.org/10.1177/0363546510379324

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Reurink, G., & van der Made, A. D. (2019). Managing the athlete with a stubborn proximal hamstring tendinopathy. Aspetar Sports Medicine Journal, 8. https://journal.aspetar.com/en/journals/volume-8-targeted-topic-sports-medicine-and-science-in-athletics/managing-the-athlete-with-a-stubborn-proximal-hamstring-tendinopathy

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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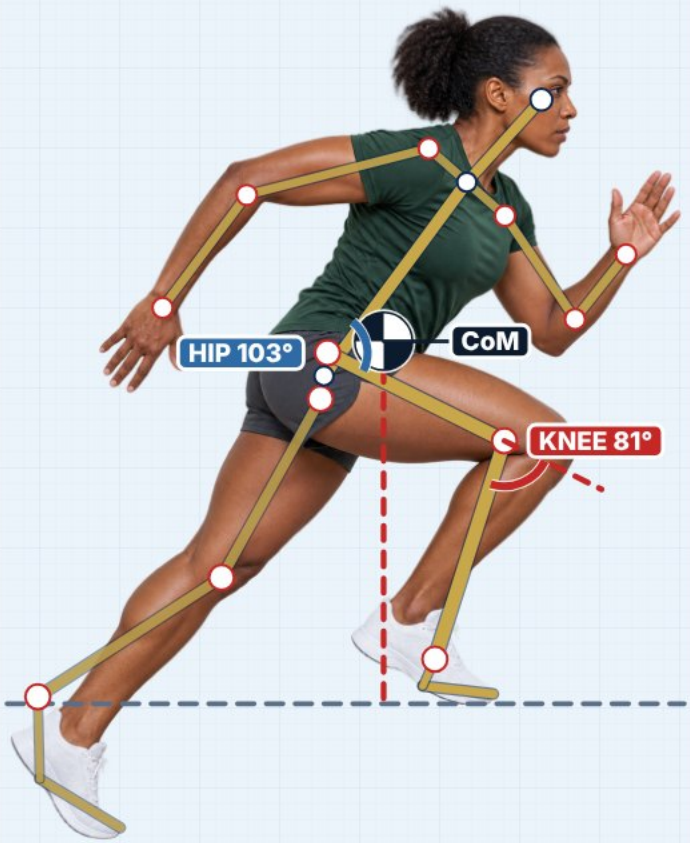
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HAMSTRING RE-INJURY: WHY IT COMES BACK AND HOW TO LOWER THE RISK

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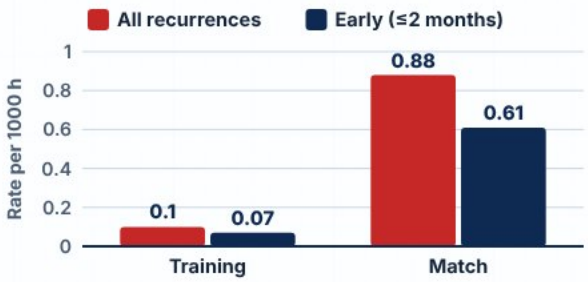
A · SPRINT ACCELERATION, SIDE



Acceleration is not low load

- Driving out of a sprint start, trunk leaning **36°**, front hip flexed **103°**: modelling shows accelerating from 50% of top speed stretches the hamstrings like steady running at 88%.
- In elite football, recurrences were far more frequent in matches, and most happened within 2 months of return.

Recurrences concentrate in matches



UEFA Elite Club Injury Study, 2001/02–2021/22. Ekstrand et al. (2023). Acceleration model: Gurchiek et al. (2024).

Key point: 69% of recurrences were early, within 2 months of returning to play.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk and hip angles from pose landmarks in the side view; sprint poses are approximate. Educational, not diagnostic.

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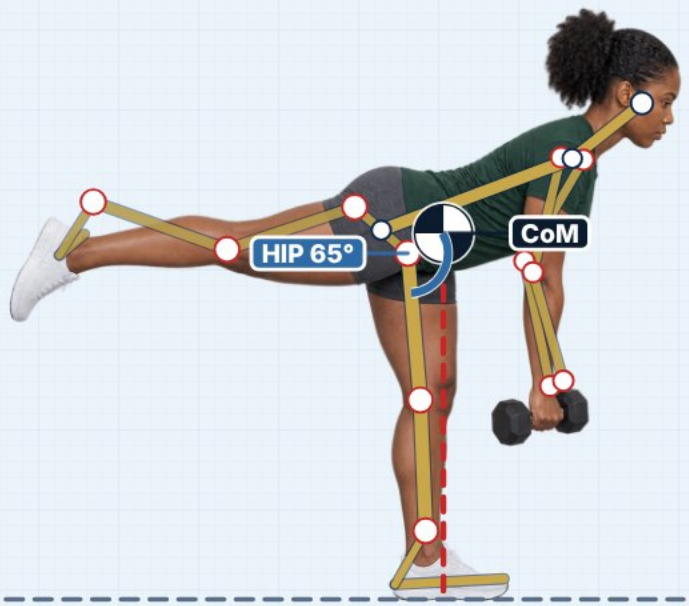
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B · SINGLE-LEG RDL, SIDE



Single-leg hinge: long-length strength

- Balancing on the left leg, trunk tilted forward, right leg reaching back, light dumbbell: the standing hip is flexed **65°** and the hamstrings hold the tilted trunk at long length.
- Rehabilitation allowing some discomfort reached clearance as fast as pain-free rehab, with two re-injuries in each group by 6 months.

Some discomfort is not harmful



Randomised trial after acute hamstring strain. Hickey et al. (2020).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip angle of the standing (left) leg from pose landmarks in the side view. Educational, not diagnostic.

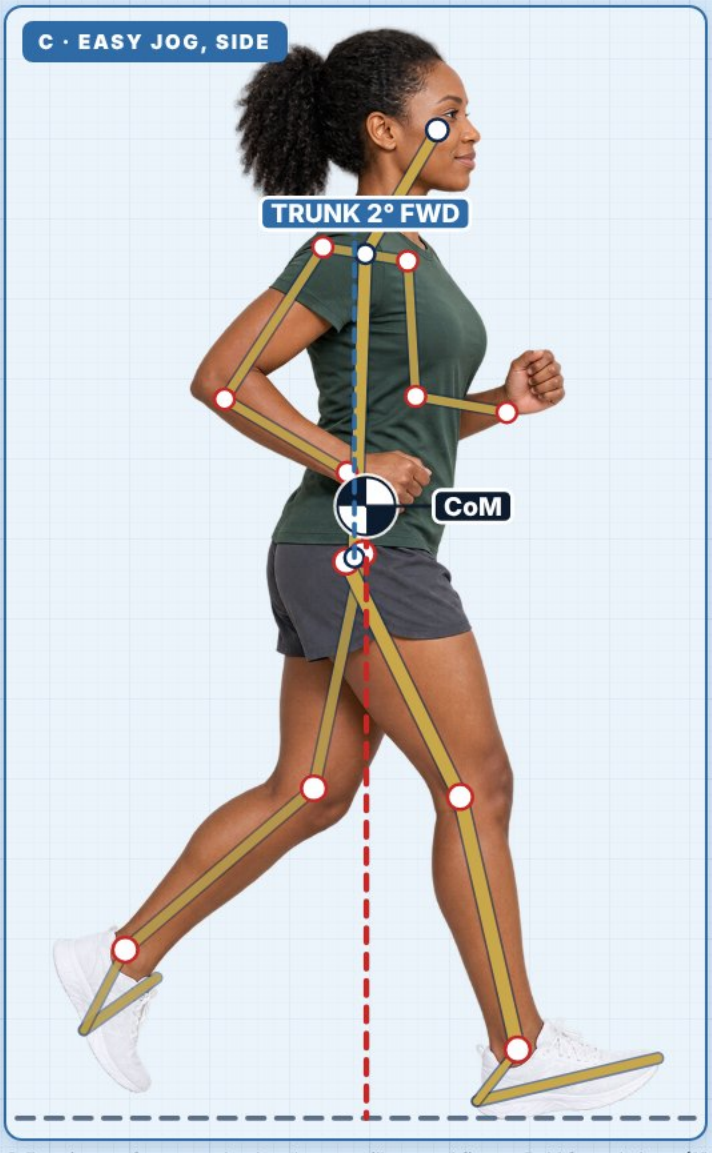
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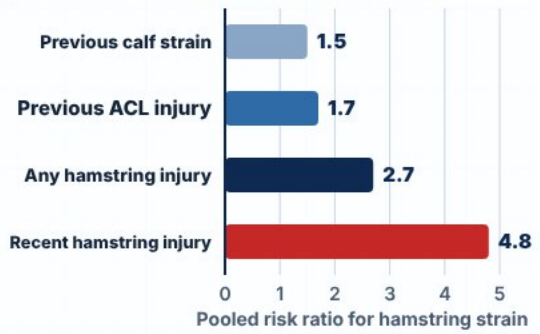
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Easy jogging: genuinely lower load

- Upright jog, trunk within **2°** of vertical, short stride: hamstring stretch is well below sprint levels, so jogging is a safe early rung on the running ladder.
- Across 78 studies, a recent hamstring injury was the strongest risk factor for another one.

A recent injury carries the most risk



78 studies, 8319 hamstring injuries (967 recurrences), 71,324 athletes; all $p \leq 0.002$. Green et al. (2020).

Myth: "Once it stops hurting, it is healed." Across studies, recurrence ranged from 13.9% to 63.3% (de Visser et al., 2012).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line from hip to shoulder points in the side view. Educational, not diagnostic.

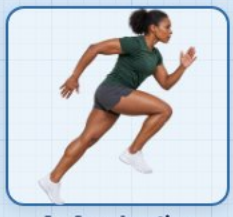
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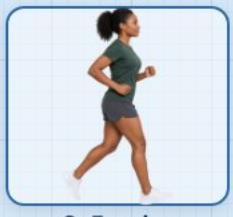
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A · Acceleration
Trunk 36° forward

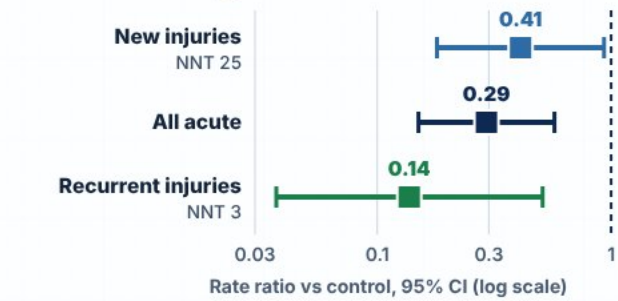


B · Single-leg RDL
Standing hip 65°



C · Easy jog
Lower hamstring stretch

Eccentric training cuts recurrences most



942 Danish footballers, 50 teams; 10-week Nordic programme, then weekly. Petersen et al. (2011).

Decision pathway

1. **CRITERIA**
   Clear return on strength and sprint criteria, not on the absence of pain.
2. **GRADE SPEED**
   Rebuild acceleration and match-speed running in steps before full matches.
3. **KEEP LOADING**
   Continue eccentric work after return; the first 2 months carry the most risk.

NOT RECOMMENDED

Stopping strength work once symptoms settle; going straight back to full matches.

SEEK ASSESSMENT IF

A second strain in the same place soon after return, tendon involvement on imaging, or thigh pain with back pain, pins and needles or numbness.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

de Visser, H. M., Reijman, M., Heijboer, R., & Bos, K. (2012). Risk factors of recurrent hamstring injuries: A systematic review. *British Journal of Sports Medicine, 46*(2), 124–130. https://doi.org/10.1136/bjsports-2011-090317

Ekstrand, J., Bengtsson, H., Waldén, M., Davison, M., Khan, K. M., & Hägglund, M. (2023). Hamstring injury rates have increased during recent seasons and now constitute 24% of all injuries in men's professional football: The UEFA Elite Club Injury Study from 2001/02 to 2021/22. *British Journal of Sports Medicine, 57*(5), 292–298. https://doi.org/10.1136/bjsports-2021-105407

Green, B., Bourne, M. N., van Dyk, N., & Pizzari, T. (2020). Recalibrating the risk of hamstring strain injury (HSI): A 2020 systematic review and meta-analysis of risk factors for index and recurrent hamstring strain injury in sport. *British Journal of Sports Medicine, 54*(18), 1081–1088. https://doi.org/10.1136/bjsports-2019-100983

Gurchiek, R. D., Teplin, Z., Falisse, A., Hicks, J. L., & Delp, S. L. (2024). Hamstrings are stretched more and faster during accelerative running compared to speed-matched constant-speed running. Medicine & Science in Sports & Exercise. https://doi.org/10.1249/MSS.0000000000003577

Hickey, J. T., Timmins, R. G., Maniar, N., Rio, E., Hickey, P. F., Pitcher, C. A., Williams, M. D., & Opar, D. A. (2020). Pain-free versus pain-threshold rehabilitation following acute hamstring strain injury: A randomized controlled trial. *Journal of Orthopaedic & Sports Physical Therapy, 50*(2), 91–103. https://doi.org/10.2519/jospt.2020.8895

Petersen, J., Thorborg, K., Nielsen, M. B., Budtz-Jørgensen, E., & Hölmich, P. (2011). Preventive effect of eccentric training on acute hamstring injuries in men's soccer: A cluster-randomized controlled trial. *The American Journal of Sports Medicine, 39*(11), 2296–2303. https://doi.org/10.1177/0363546511419277

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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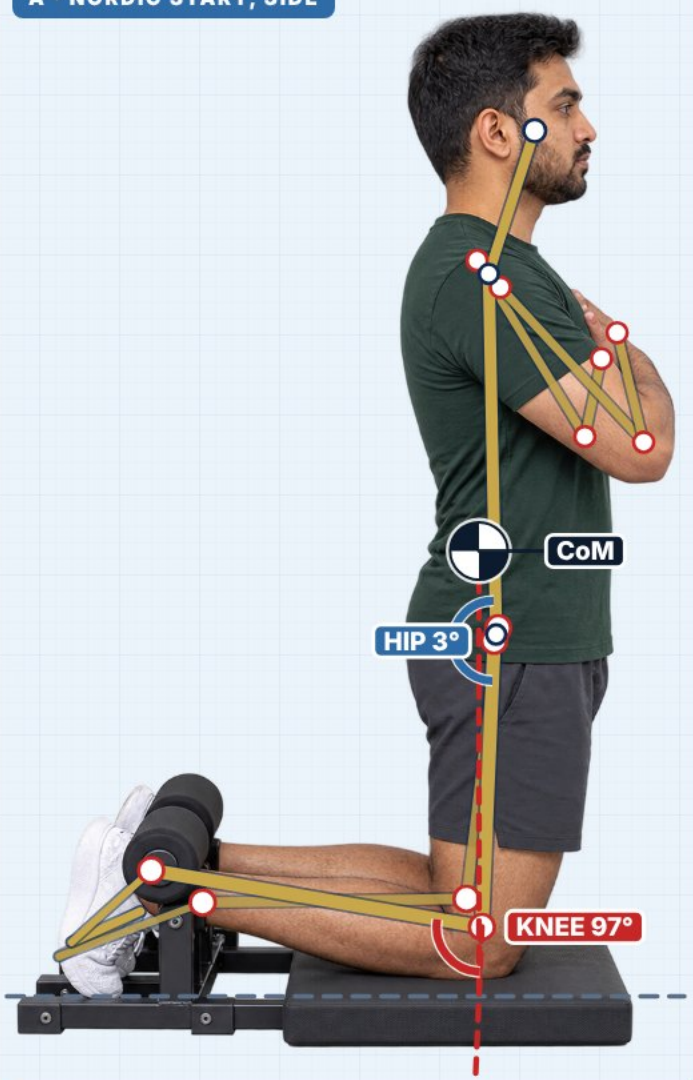
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NORDIC HAMSTRING CURL: WHAT THE INJURY-PREVENTION EVIDENCE SHOWS

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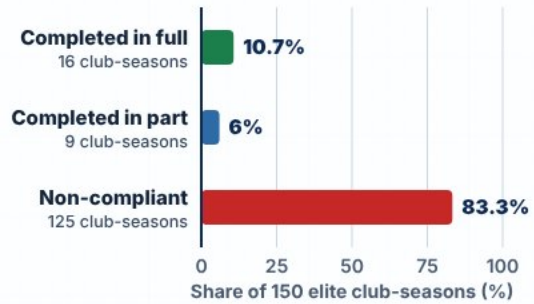
A · NORDIC START, SIDE



Start: kneeling tall, ankles anchored

- Kneeling on a pad with the heels fixed under rollers and arms crossed, hip within **3°** of straight and knees bent **97°**: the body forms one line from knee to head.
- The exercise is simple and cheap, yet most elite football teams surveyed did not complete the programme.

The implementation gap



50 professional teams (Champions League and Norwegian top division), 2012–2014; 100% response. Bahr et al. (2015).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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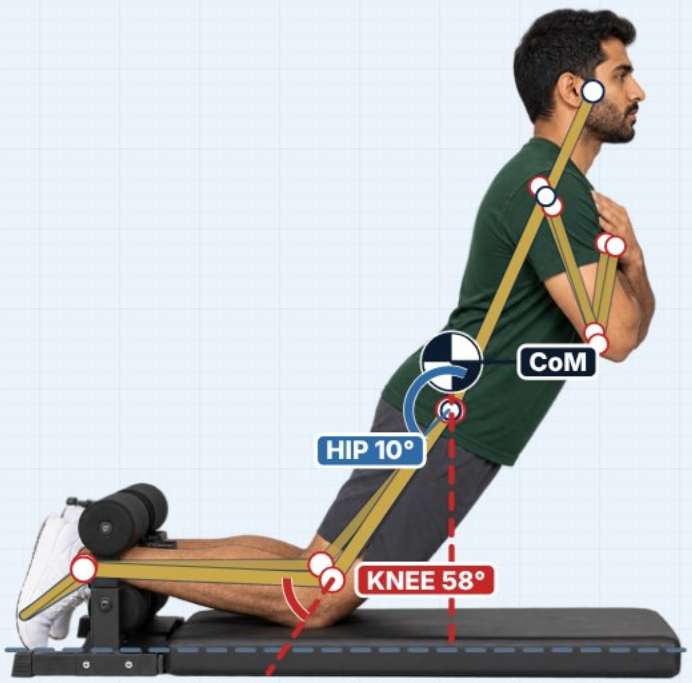
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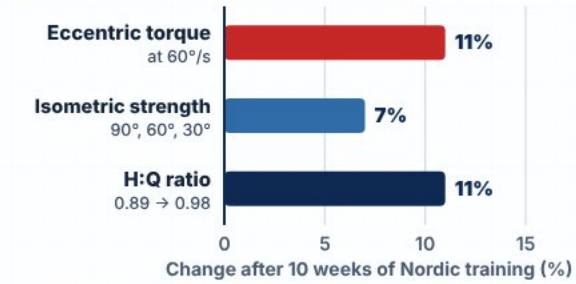
B · NORDIC LOWERING, SIDE



Lowering: braking with the hamstrings

- Leaning forward from the knees with the body straight, knee angle now **58°**: the hamstrings lengthen under rising load as they resist the fall.
- On functional MRI the Nordic loaded semitendinosus most, so hip-extension exercises are still needed for biceps femoris.

What 10 weeks of Nordics change



21 well-trained footballers, Nordic vs concentric curls; eccentric gains greater with Nordics. Mjølsnes et al. (2004). MRI: Bourne et al. (2017).

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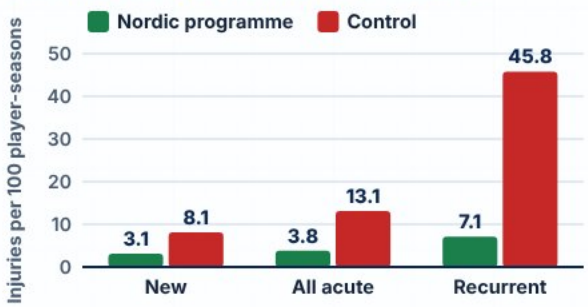
C · NORDIC CATCH, SIDE



The catch: end of the range

- Body nearly horizontal, hands catching on the mat: the knee is close to straight, the longest and hardest point of the lowering.
- In a cluster-randomised trial, the programme reduced new and, most of all, recurrent hamstring injuries.

Fewer injuries, especially repeat ones



942 Danish footballers, 50 teams; number needed to treat 13 for one injury. Petersen et al. (2011).

Myth: "It only works if you control the whole range." Trials used gradual, partner-assisted programmes; pooled risk was about halved (van Dyk et al., 2019).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Near-prone pose: skeleton only; joint angles not reported. Educational, not diagnostic.

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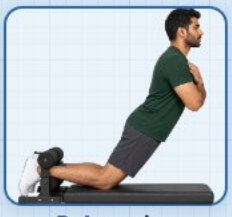
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A · Start
Knee 97°

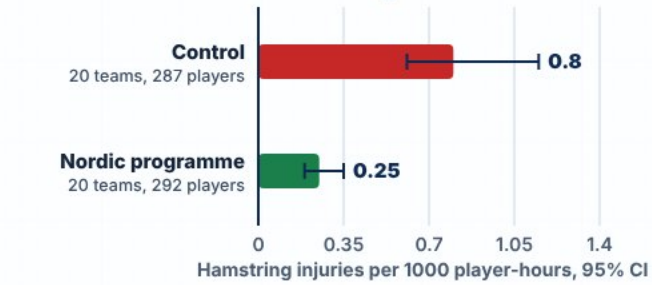


B · Lowering
Knee 58°



C · Catch
Knee near straight

Amateur trial: incidence cut by two-thirds



25 Nordic sessions in 13 weeks, 91% compliance; odds ratio 0.282 (95% CI 0.110–0.721). van der Horst et al. (2015).

Decision pathway

1. **INCLUDE**
   Add the Nordic, or a programme containing it, to team-sport prevention.
2. **PROGRESS**
   Build volume gradually, e.g. from 2 × 6 to 3 × 8–12 over 4 weeks, to limit soreness.
3. **COMPLY**
   Benefits came with high compliance; pair it with hip-extension exercises.

NOT RECOMMENDED

Starting with high volume; dropping the programme mid-season.

SEEK ASSESSMENT IF

Sudden sharp thigh pain during the exercise, or soreness with marked swelling, very dark urine or severe weakness.

REFERENCES (APA 7)

Bahr, R., Thorborg, K., & Ekstrand, J. (2015). Evidence-based hamstring injury prevention is not adopted by the majority of Champions League or Norwegian Premier League football teams: The Nordic Hamstring survey. *British Journal of Sports Medicine, 49*(22), 1466–1471. https://doi.org/10.1136/bjsports-2015-094826

Bourne, M. N., Williams, M. D., Opar, D. A., Al Najjar, A., Kerr, G. K., & Shield, A. J. (2017). Impact of exercise selection on hamstring muscle activation. *British Journal of Sports Medicine, 51*(13), 1021–1028. https://doi.org/10.1136/bjsports-2015-095739

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Mjølsnes, R., Arnason, A., Østhagen, T., Raastad, T., & Bahr, R. (2004). A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. *Scandinavian Journal of Medicine & Science in Sports, 14*(5), 311–317. https://doi.org/10.1046/j.1600-0838.2003.367.x

Petersen, J., Thorborg, K., Nielsen, M. B., Budtz-Jørgensen, E., & Hölmich, P. (2011). Preventive effect of eccentric training on acute hamstring injuries in men's soccer: A cluster-randomized controlled trial. *The American Journal of Sports Medicine, 39*(11), 2296–2303. https://doi.org/10.1177/0363546511419277

van der Horst, N., Smits, D.-W., Petersen, J., Goedhart, E. A., & Backx, F. J. G. (2015). The preventive effect of the Nordic hamstring exercise on hamstring injuries in amateur soccer players: A randomized controlled trial. *The American Journal of Sports Medicine, 43*(6), 1316–1323. https://doi.org/10.1177/0363546515574057

van Dyk, N., Behan, F. P., & Whiteley, R. (2019). Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: A systematic review and meta-analysis of 8459 athletes. *British Journal of Sports Medicine, 53*(21), 1362–1370. https://doi.org/10.1136/bjsports-2018-100045

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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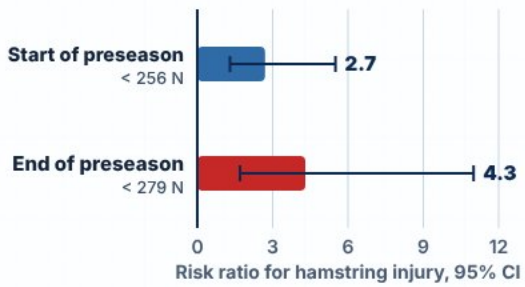
A · SLIDER LEG CURL, SIDE



Sliders: control while lengthening

- Lying in a bridge with the heels on sliding discs, legs sliding out until the knees are nearly straight (≈**25°** flexion): the hamstrings lengthen while holding the hips up.
- In elite Australian footballers, low eccentric knee-flexor strength in a Nordic test was linked with a higher risk of later hamstring injury.

Weak eccentric strength, higher risk



210 elite Australian footballers; wide intervals reflect few injuries. Opar et al. (2015).

Myth: "Equal legs mean safe hamstrings." A between-leg difference above 10% did not increase risk in the same cohort.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Lying pose: knee angle approximate; hip angle not reported. Educational, not diagnostic.

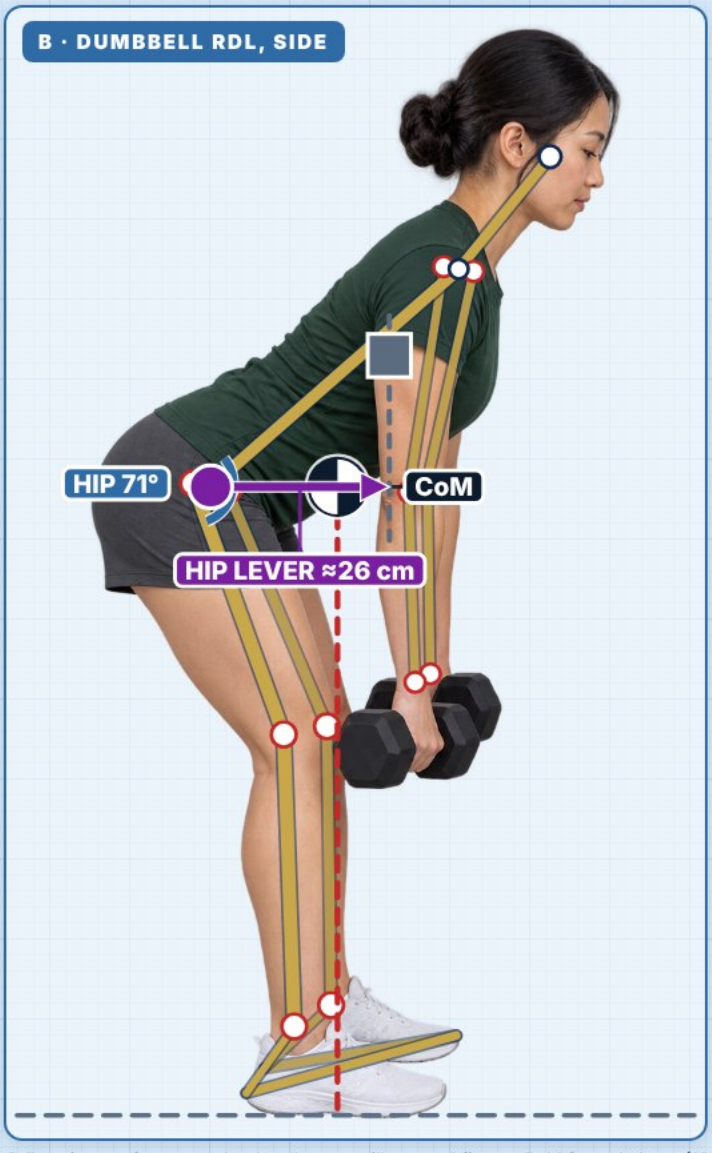
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INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

ECCENTRIC HAMSTRING STRENGTH: WHY LENGTHENING CONTROL MATTERS

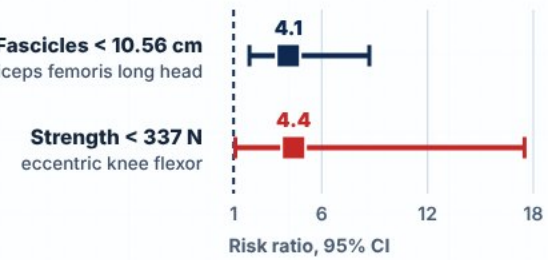
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The hinge trains the long position

- Romanian deadlift with two dumbbells, hip flexed **71°** and knees soft: hip lever **≈26 cm**, hip moment **≈102 N·m** before the dumbbells, held at long hamstring length.
- In elite football, short biceps femoris fascicles and low eccentric strength were each linked with about a four-fold injury risk.

Muscle structure and strength both count



152 elite football players, prospective cohort. Timmins et al. (2016).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Dumbbell load not included. Educational, not diagnostic.

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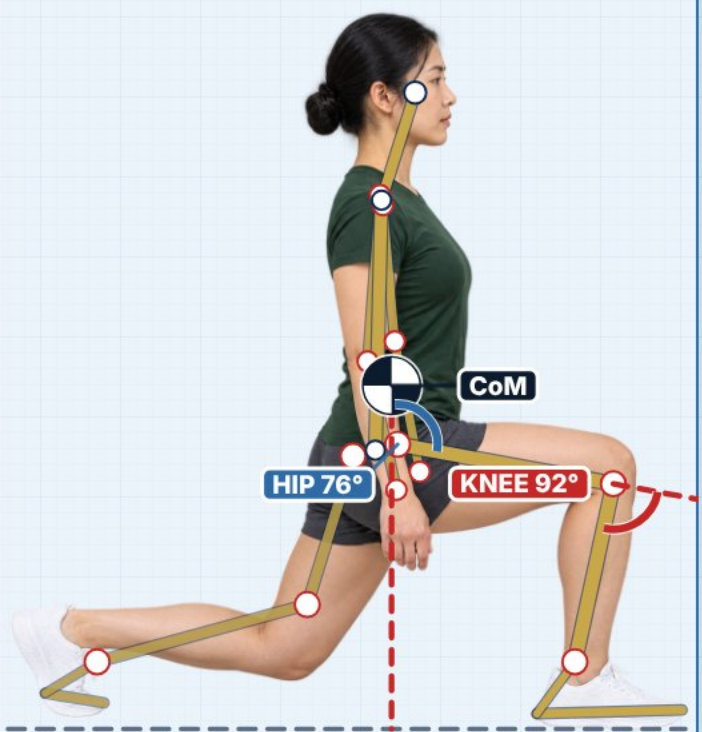
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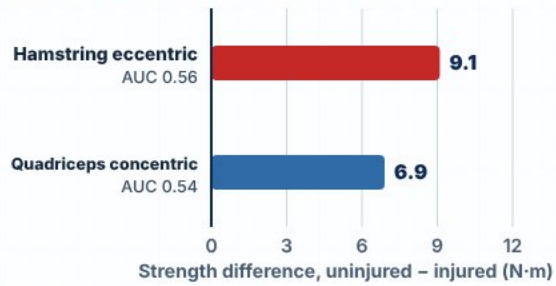
C · WALKING LUNGE, SIDE



Lunges: everyday lengthening control

- Long walking lunge with the trunk upright, front hip flexed **76°** and knee **92°**: hip and knee extensors control the descent of the body.
- In a large professional cohort, players who were injured were only slightly weaker beforehand (effect size d < 0.2).

Small differences before injury



614 professional footballers, 190 hamstring injuries over 4 seasons. van Dyk et al. (2016).

Key point: eccentric strength is a modifiable target, not a crystal ball for one athlete.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Front-leg hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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A · Slider curl
Knee ≈25°

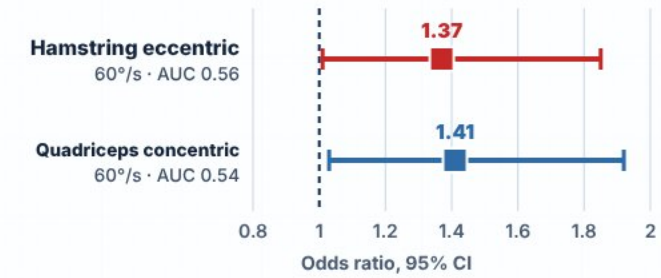


B · Dumbbell RDL
≈102 N·m at the hip



C · Walking lunge
Knee 92°

Train it rather than screen with it



Isokinetic strength adjusted for body weight; AUC near 0.5 means close to chance. van Dyk et al. (2016).

Decision pathway

1. **BUILD**
   Progress eccentric work: Nordics, slider curls and Romanian deadlifts.
2. **REHAB**
   Lengthened-position loading after a strain shortened return to play (Askling et al., 2013).
3. **INTERPRET**
   Do not use one strength number or a >10% side difference as a pass or fail test.

NOT RECOMMENDED

Using strength symmetry alone to clear an athlete; heavy eccentric work without a gradual build.

SEEK ASSESSMENT IF

Sudden pain during eccentric work, inability to bear weight, marked bruising, or numbness or tingling in the leg.

REFERENCES (APA 7)

Askling, C. M., Tengvar, M., & Thorstensson, A. (2013). Acute hamstring injuries in Swedish elite football: A prospective randomised controlled clinical trial comparing two rehabilitation protocols. *British Journal of Sports Medicine, 47*(15), 953–959. https://doi.org/10.1136/bjsports-2013-092165

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Opar, D. A., Williams, M. D., Timmins, R. G., Hickey, J., Duhig, S. J., & Shield, A. J. (2015). Eccentric hamstring strength and hamstring injury risk in Australian footballers. *Medicine & Science in Sports & Exercise, 47*(4), 857–865. https://doi.org/10.1249/MSS.0000000000000465

Timmins, R. G., Bourne, M. N., Shield, A. J., Williams, M. D., Lorenzen, C., & Opar, D. A. (2016). Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): A prospective cohort study. *British Journal of Sports Medicine, 50*(24), 1524–1535. https://doi.org/10.1136/bjsports-2015-095362

van Dyk, N., Bahr, R., Whiteley, R., Tol, J. L., Kumar, B. D., Hamilton, B., Farooq, A., & Witvrouw, E. (2016). Hamstring and quadriceps isokinetic strength deficits are weak risk factors for hamstring strain injuries: A 4-year cohort study. *The American Journal of Sports Medicine, 44*(7), 1789–1795. https://doi.org/10.1177/0363546516632526

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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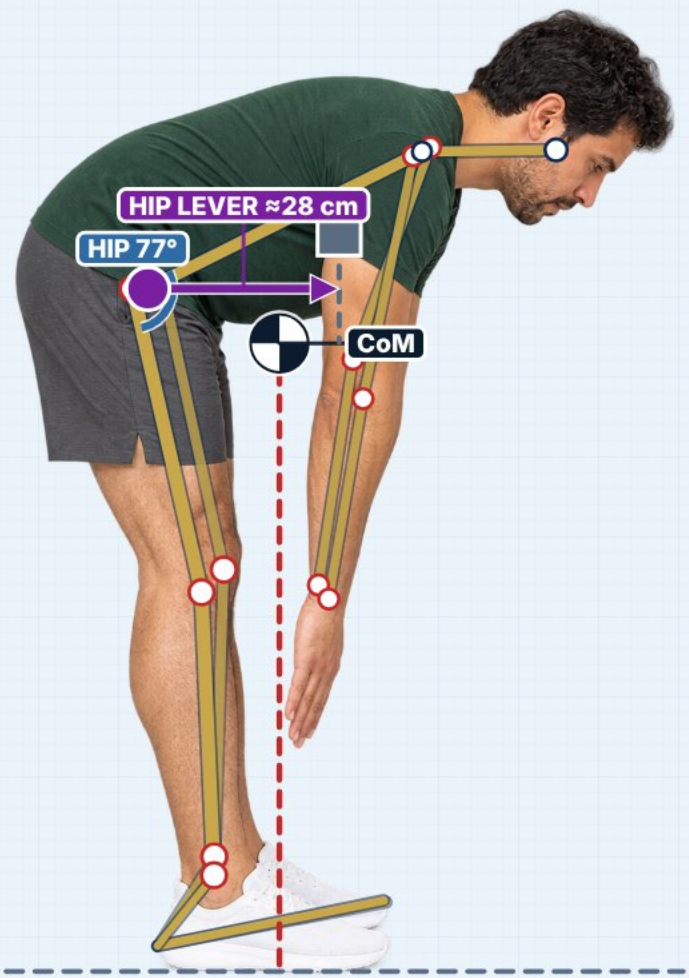
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TIGHT HAMSTRINGS: STIFFNESS, PROTECTIVE TENSION OR NERVE SENSITIVITY?

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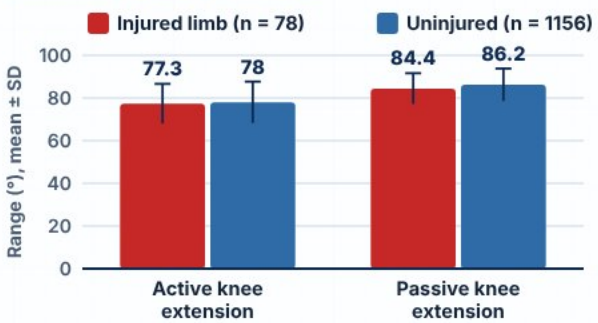
A · TOE-TOUCH ATTEMPT, SIDE



A short reach is not a diagnosis

- Bending with straight knees, fingertips only to mid-shin, hip flexed **77°**: hip lever ≈**28 cm**, hip moment ≈**117 N·m**. Limited reach can reflect stiffness, stretch tolerance, muscle guarding or nerve sensitivity.
- Injured professional players had almost the same flexibility beforehand as players who stayed uninjured.

Flexibility barely differed



438 professional players, 78 hamstring injuries; passive difference 1.8°, d < 0.2. van Dyk et al. (2018).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Educational, not diagnostic.

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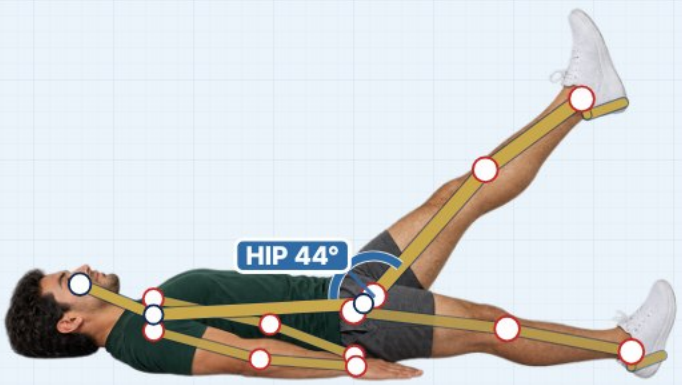
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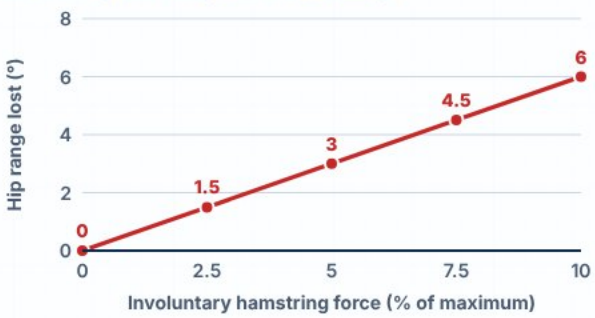
B · STRAIGHT-LEG RAISE, SIDE



Straight-leg raise: tension can be protective

- Lying on the back, one leg raised straight with the hip flexed about **44°**, the other flat: the range stops when stretch, guarding or nerve symptoms say so.
- Small involuntary hamstring activity cut passive straight-leg raise range by 0.6° for every 1% of maximal force.

Muscle guarding reduces range



30 healthy adults, hamstrings stimulated during a passive raise; values from the published slope (95% CI 0.3–0.9° per 1%). Foo et al. (2019).

Key point: add ankle dorsiflexion or neck flexion to the raise to help reveal a nerve contribution.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Lying pose: leg landmarks placed by hand; hip angle approximate. Educational, not diagnostic.

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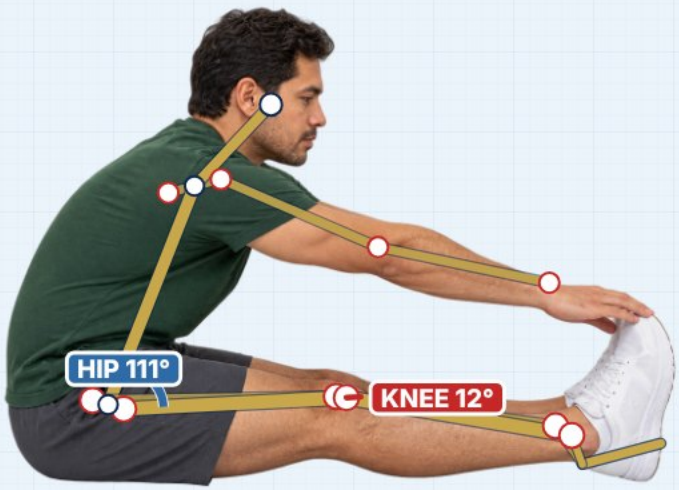
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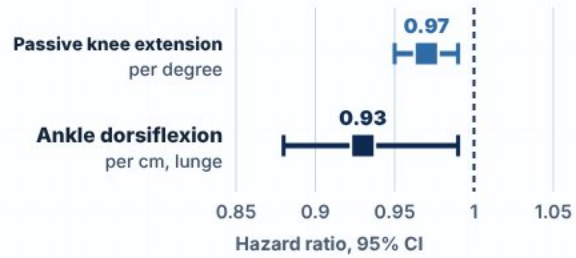
C · SIT-AND-REACH, SIDE



Sit-and-reach: a weak predictor

- Sitting with straight legs (knee ≈**12°**), reaching to the toes with the hip flexed **111°** and the back rounded: the score mixes hip, spine and nerve mobility.
- In 450 amateur footballers, sit-and-reach (mean 21.2 ± 9.2 cm) was not related to hamstring injury over a season.

Tiny effects per unit of range



Professional cohort as on slide 1; ratios below 1 mean slightly lower risk with more range. van Dyk et al. (2018). Sit-and-reach: van Doormaal et al. (2017).

Myth: "Stretching makes short hamstrings longer." It mainly raised stretch tolerance, not length or stiffness (Halbertsma & Göeken, 1994).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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A · Toe touch
Hip 77°

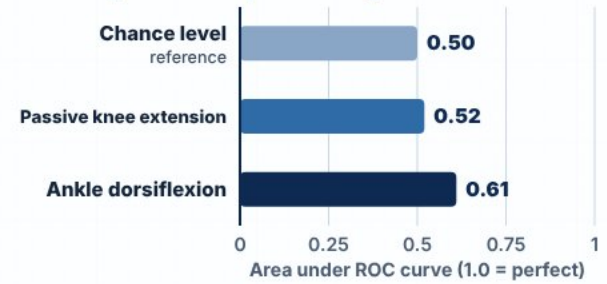


B · Straight-leg raise
Hip ≈44°



C · Sit-and-reach
Hip 111°

Flexibility does not pick who gets hurt



438 professional players, 78 injuries; the 0.50 chance line is a standard reference. van Dyk et al. (2018).

Decision pathway

1. **ASSESS**
   Compare toe-touch, straight-leg raise and sit-and-reach, adding nerve-sensitising moves.
2. **CLASSIFY**
   Decide whether stiffness, guarding, stretch tolerance or nerve sensitivity fits best.
3. **STRENGTHEN**
   For injury prevention, prioritise strength; flexibility screening predicts poorly.

NOT RECOMMENDED

Labelling all "tightness" as short muscle and stretching hard into nerve symptoms.

SEEK ASSESSMENT IF

Back pain with pain below the knee, pins and needles, numbness or weakness, a sudden one-sided loss of range, or saddle numbness or bladder or bowel change (urgent).

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Foo, Y., Héroux, M. E., Chia, L., & Diong, J. (2019). Involuntary hamstring muscle activity reduces passive hip range of motion during the straight leg raise test: A stimulation study in healthy people. BMC Musculoskeletal Disorders, 20. https://doi.org/10.1186/s12891-019-2511-6

Halbertsma, J. P., & Göeken, L. N. (1994). Stretching exercises: Effect on passive extensibility and stiffness in short hamstrings of healthy subjects. *Archives of Physical Medicine and Rehabilitation, 75*(9), 976–981. https://doi.org/10.1016/0003-9993(94)90675-0

van Doormaal, M. C. M., van der Horst, N., Backx, F. J. G., Smits, D.-W., & Huisstede, B. M. A. (2017). No relationship between hamstring flexibility and hamstring injuries in male amateur soccer players. *The American Journal of Sports Medicine, 45*(1), 121–126. https://doi.org/10.1177/0363546516664162

van Dyk, N., Farooq, A., Bahr, R., & Witvrouw, E. (2018). Hamstring and ankle flexibility deficits are weak risk factors for hamstring injury in professional soccer players: A prospective cohort study of 438 players including 78 injuries. *The American Journal of Sports Medicine, 46*(9), 2203–2210. https://doi.org/10.1177/0363546518773057

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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HAMSTRING STRETCHING: DOES IT PREVENT INJURY OR JUST CHANGE TOLERANCE?

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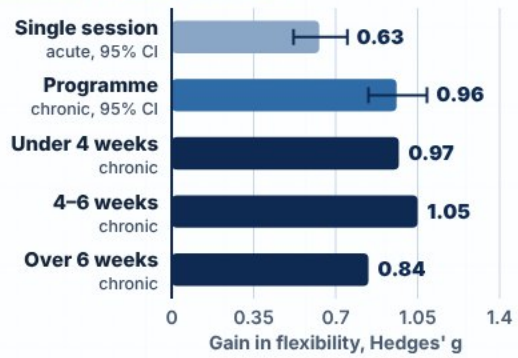
A · HEEL-ON-STEP STRETCH, SIDE



Stretching does increase range

- Right heel on a low step, knee straight, leaning forward from the hips with a flat back: the front hip flexes about **84°**, lengthening the hamstrings over both joints.
- Across 189 studies, single sessions and programmes both improved flexibility; gains peaked at about 4 min per session or 10 min per week.

Flexibility gains are real



189 studies, 6654 adults; weekly frequency had no effect (g −0.001). Ingram et al. (2025).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip angle: trunk line to the forward (right) thigh in the side view. Educational, not diagnostic.

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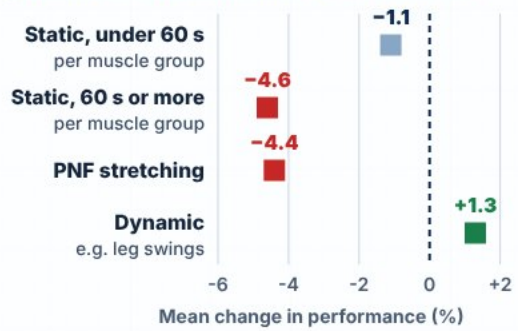
B · STRAP STRETCH, SIDE



Range gains are mostly tolerance

- Lying on her back, the right leg is drawn up with a strap around the foot while the left leg stays flat: a controlled, passive hamstring stretch.
- Over 3–8 weeks, the extra range appears to come mainly from greater tolerance of the stretch sensation, not from a less stiff muscle or tendon.

Long holds blunt immediate performance



Healthy active people tested about 3–5 min after stretching; mean changes. Behm et al. (2016).

Key point: in a warm-up, short static holds and dynamic swings cost little; save long holds for separate flexibility work.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Lying pose: no angles reported. Tolerance finding from Freitas et al. (2018). Educational, not diagnostic.

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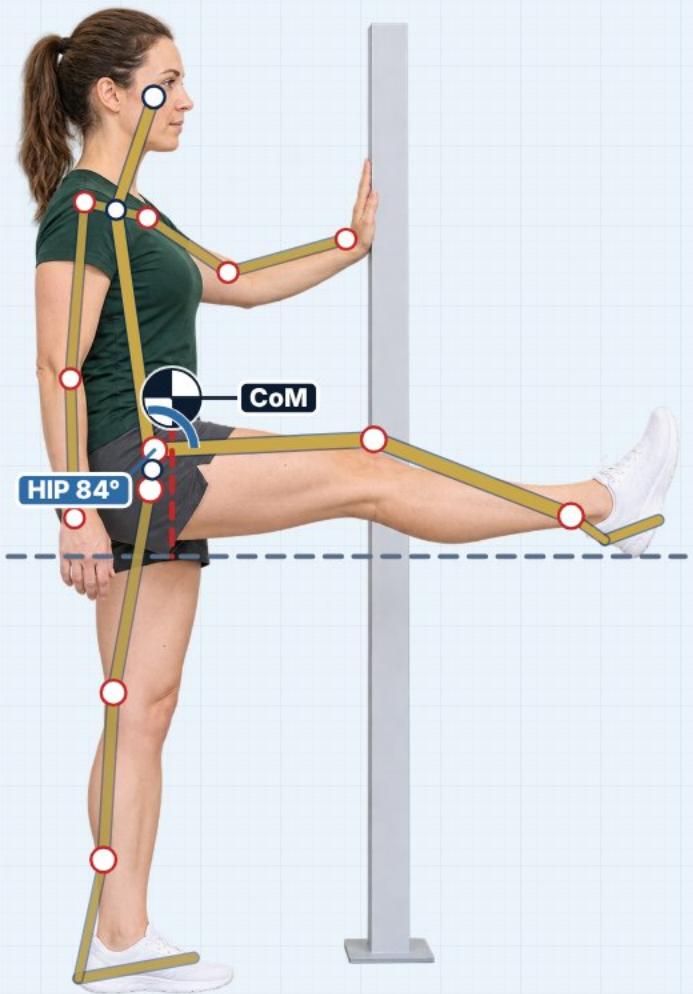
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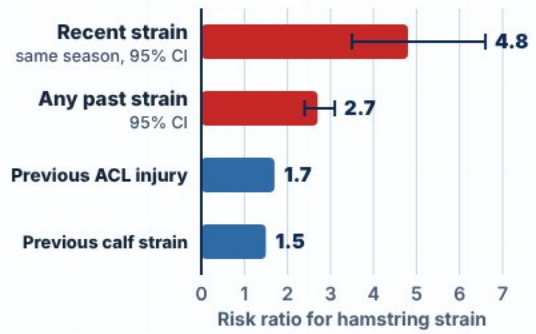
C · LEG SWING, SIDE



Dynamic swings as warm-up

- Hand on a post, the right leg swings forward to about hip height, hip flexed near **84°**: a dynamic stretch that rehearses the range used in running.
- In 78 studies, flexibility scores (active knee extension, straight-leg raise) showed no clear link with hamstring strain; previous injury did.

History predicts risk; flexibility does not



78 studies, 71,324 athletes, 8319 hamstring injuries. Green et al. (2020); CIs as reported by Martin et al. (2022).

Myth: "Stretching your hamstrings prevents tears." Pooled trials show no protective effect; flexibility is not a clear risk factor.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip angle: trunk line to the swinging (right) thigh; a moving pose, so approximate. Educational, not diagnostic.

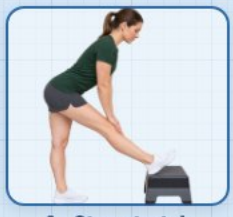
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A · Step stretch
Hip ≈84°

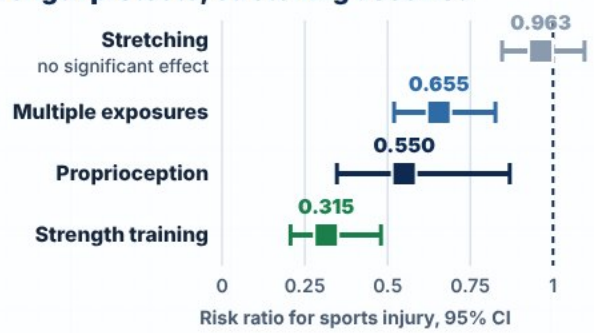


B · Strap stretch
Tolerance rises



C · Leg swing
Warm-up range

Strength protects; stretching does not



25 randomised trials, 26,610 participants, 3464 injuries (all sports injuries). Lauersen et al. (2014).

Decision pathway

1. **PREVENT**
   Build strength, including the Nordic exercise, within a multi-component programme.
2. **STRETCH FOR RANGE**
   Use about 4 min per session or 10 min per week when range itself is the goal.
3. **WARM UP**
   Prefer dynamic swings and short holds before sprinting; keep long holds for separate sessions.

NOT RECOMMENDED

Relying on stretching alone to prevent hamstring strains; long static holds just before sprinting.

SEEK ASSESSMENT IF

Sudden pain at the back of the thigh during activity, bruising or swelling, or a stretch that brings on burning, tingling or symptoms below the knee.

REFERENCES (APA 7)

Behm, D. G., Blazevich, A. J., Kay, A. D., & McHugh, M. (2016). Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: A systematic review. *Applied Physiology, Nutrition, and Metabolism, 41*(1), 1–11. https://doi.org/10.1139/apnm-2015-0235

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Freitas, S. R., Mendes, B., Le Sant, G., Andrade, R. J., Nordez, A., & Milanovic, Z. (2018). Can chronic stretching change the muscle-tendon mechanical properties? A review. *Scandinavian Journal of Medicine & Science in Sports, 28*(3), 794–806. https://doi.org/10.1111/sms.12957

Green, B., Bourne, M. N., van Dyk, N., & Pizzari, T. (2020). Recalibrating the risk of hamstring strain injury (HSI): A 2020 systematic review and meta-analysis of risk factors for index and recurrent hamstring strain injury in sport. *British Journal of Sports Medicine, 54*(18), 1081–1088. https://doi.org/10.1136/bjsports-2019-100983

Ingram, L. A., Tomkinson, G. R., d'Unienville, N. M. A., Gower, B., Gleadhill, S., Boyle, T., & Bennett, H. (2025). Optimising the dose of static stretching to improve flexibility: A systematic review, meta-analysis and multivariate meta-regression. *Sports Medicine, 55*(3), 597–617. https://doi.org/10.1007/s40279-024-02143-9

Lauersen, J. B., Bertelsen, D. M., & Andersen, L. B. (2014). The effectiveness of exercise interventions to prevent sports injuries: A systematic review and meta-analysis of randomised controlled trials. *British Journal of Sports Medicine, 48*(11), 871–877. https://doi.org/10.1136/bjsports-2013-092538

Martin, R. L., Cibulka, M. T., Bolgla, L. A., Koc, T. A., Jr., Loudon, J. K., Manske, R. C., Weiss, L., Christoforetti, J. J., & Heiderscheit, B. C. (2022). Hamstring strain injury in athletes: Clinical practice guidelines. *Journal of Orthopaedic & Sports Physical Therapy, 52*(3), CPG1–CPG44. https://doi.org/10.2519/jospt.2022.0301

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

RETURN TO RUNNING AFTER A HAMSTRING STRAIN: CRITERIA, NOT CALENDAR DAYS

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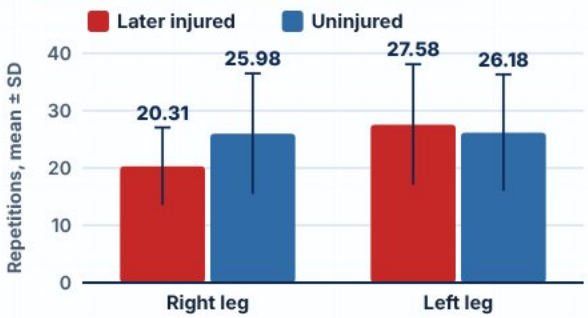
A · SINGLE-LEG BRIDGE, SIDE



A field test, not a date

- Lying on his back, left foot on the floor with the knee bent, right leg straight in the air and hips lifted: the single-leg bridge loads the hamstrings of the support leg.
- Repetitions to fatigue are one of the field tests in consensus return-to-play criteria; in the source study, fewer than 20 is poor, about 25 average, over 30 good.

Fewer reps before injury (right side)



482 Australian footballers, 28 hamstring injuries; right side p = 0.029, left side not significant (n = 12). Freckleton et al. (2014).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Lying pose: no angles reported. Return-to-play criteria from van der Horst et al. (2017). Educational, not diagnostic.

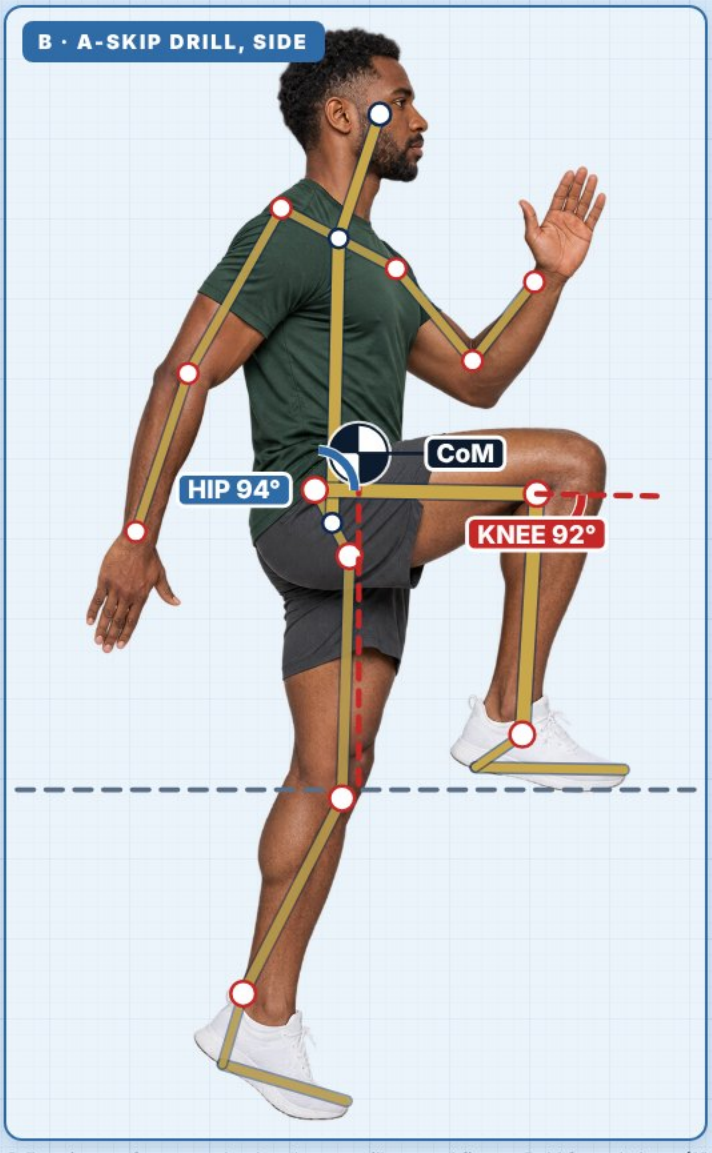
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Drills bridge rehab and running

- A-skip with the right hip flexed about **94°** and knee about **92°**, on the ball of the left foot: rhythm and posture rehearsed before speed is added.
- Loading up to a pain threshold did not delay clearance (P = .37) and gave 15% better knee-flexor strength recovery than pain-free loading.

Some pain did not slow return



43 men with acute hamstring strain, randomised; 2 reinjuries per group by 6 months. Hickey et al. (2020).

Key point: pain during loading is a guide to dose, not an automatic stop sign, within an agreed threshold.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles of the raised (right) leg from pose landmarks in the side view. Educational, not diagnostic.

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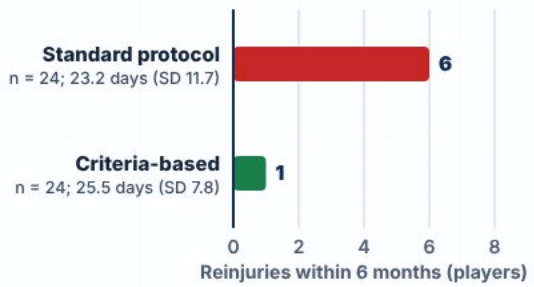
C · STRIDE RUN, SIDE



Progress speed by criteria

- Upright running at moderate pace, front hip flexed about **44°** and front knee about **27°**: a stage before repeated sprints and match-speed work.
- A criteria-based algorithm took about two days longer than a standard protocol but cut reinjuries, with better 10 m time and top speed at return.

Two extra days, fewer reinjuries



Football players; mean days to return shown under each group. Mendiguchia et al. (2017).

Myth: "Three weeks and you can sprint again." Return times ranged from 23 to 74 days across groups in one trial.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles of the front leg from pose landmarks; running poses are approximate. Myth data: Askling et al. (2013). Educational, not diagnostic.

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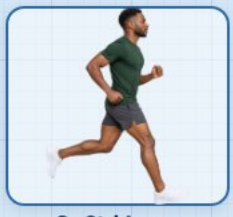
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A · Single-leg bridge
Field test

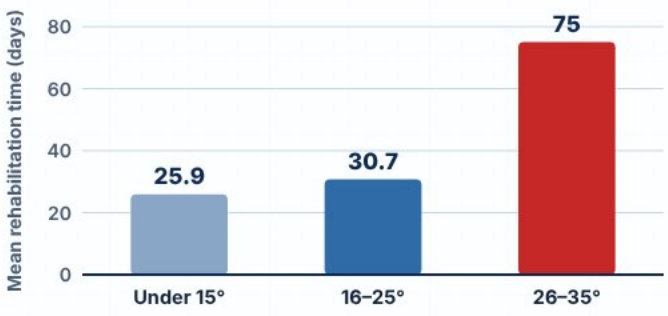


B · A-skip
Hip ≈94°



C · Stride run
Build speed

Knee-extension deficit at assessment



Active knee extension deficit with the hip at 90°; guideline citing a primary study. Martin et al. (2022).

Decision pathway

1. **MEASURE**
   Record pain, knee-flexor strength (dynamometer) and active knee extension, not days since injury.
2. **PROGRESS**
   Add eccentric work, agility and trunk control; raise running speed as each stage stays pain-free.
3. **CLEAR**
   Return when field tests, matched flexibility and psychological readiness are met; MRI is not a criterion.

NOT RECOMMENDED

Clearing on calendar days alone or on MRI appearance; skipping eccentric and sprint stages.

SEEK ASSESSMENT IF

A complete tear is suspected (diffuse swelling, a palpable gap, unable to walk), pain worsens as running progresses, or pain at night or rest.

REFERENCES (APA 7)

Askling, C. M., Tengvar, M., & Thorstensson, A. (2013). Acute hamstring injuries in Swedish elite football: A prospective randomised controlled clinical trial comparing two rehabilitation protocols. *British Journal of Sports Medicine, 47*(15), 953–959. https://doi.org/10.1136/bjsports-2013-092165

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Freckleton, G., Cook, J., & Pizzari, T. (2014). The predictive validity of a single leg bridge test for hamstring injuries in Australian Rules Football players. *British Journal of Sports Medicine, 48*(8), 713–717. https://doi.org/10.1136/bjsports-2013-092356

Hickey, J. T., Timmins, R. G., Maniar, N., Rio, E., Hickey, P. F., Pitcher, C. A., Williams, M. D., & Opar, D. A. (2020). Pain-free versus pain-threshold rehabilitation following acute hamstring strain injury: A randomized controlled trial. *Journal of Orthopaedic & Sports Physical Therapy, 50*(2), 91–103. https://doi.org/10.2519/jospt.2020.8895

Martin, R. L., Cibulka, M. T., Bolgla, L. A., Koc, T. A., Jr., Loudon, J. K., Manske, R. C., Weiss, L., Christoforetti, J. J., & Heiderscheit, B. C. (2022). Hamstring strain injury in athletes: Clinical practice guidelines. *Journal of Orthopaedic & Sports Physical Therapy, 52*(3), CPG1–CPG44. https://doi.org/10.2519/jospt.2022.0301

Mendiguchia, J., Martinez-Ruiz, E., Edouard, P., Morin, J.-B., Martinez-Martinez, F., Idoate, F., & Mendez-Villanueva, A. (2017). A multifactorial, criteria-based progressive algorithm for hamstring injury treatment. *Medicine & Science in Sports & Exercise, 49*(7), 1482–1492. https://doi.org/10.1249/MSS.0000000000001241

van der Horst, N., Backx, F. J. G., Goedhart, E. A., & Huisstede, B. M. A. (2017). Return to play after hamstring injuries in football (soccer): A worldwide Delphi procedure regarding definition, medical criteria and decision-making. *British Journal of Sports Medicine, 51*(22), 1583–1591. https://doi.org/10.1136/bjsports-2016-097206

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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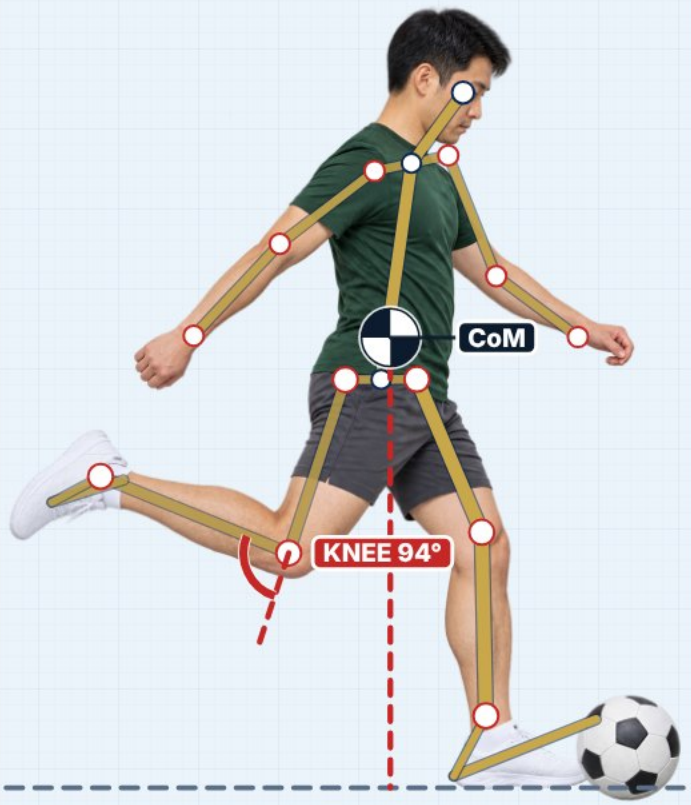
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HAMSTRING INJURY IN FOOTBALLERS: HIGH-SPEED RUNNING AND FATIGUE

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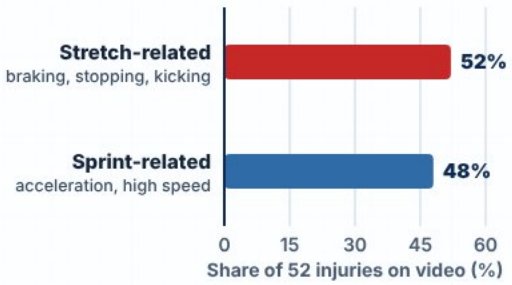
A · KICK BACKSWING, SIDE



Kicking loads the hamstrings too

- Backswing with the right knee bent about **94°** and the left foot planted beside the ball: the hamstrings will soon brake a fast-extending knee in the follow-through.
- In professional football video, about half of hamstring injuries were stretch-related, and biceps femoris was involved in 79%.

Not only a sprinting injury



52 hamstring injuries, German top two divisions, 2014–2019. Gronwald et al. (2022).

Myth: "Hamstring injuries only happen when sprinting." Stretch-type actions such as braking and kicking caused 27 of 52.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle of the kicking (right) leg from pose landmarks; hip angle not reported for this pose. Educational, not diagnostic.

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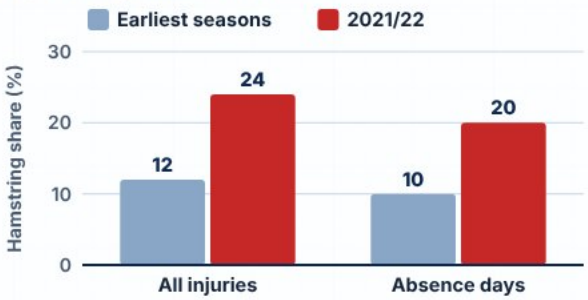
B · KICK FOLLOW-THROUGH, SIDE



Follow-through: long and fast

- Kicking leg swung forward and up, hip flexed about **84°** with the knee near straight (**20°**): the hamstrings are long while braking the leg.
- Over 21 seasons of elite European football, the hamstring share of all injuries and of absence days roughly doubled.

A growing share of injuries



UEFA Elite Club Injury Study, 3909 players, 2636 hamstring injuries, 2001/02–2021/22. Ekstrand et al. (2023).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles of the kicking (right) leg; a fast movement, so angles are approximate. Educational, not diagnostic.

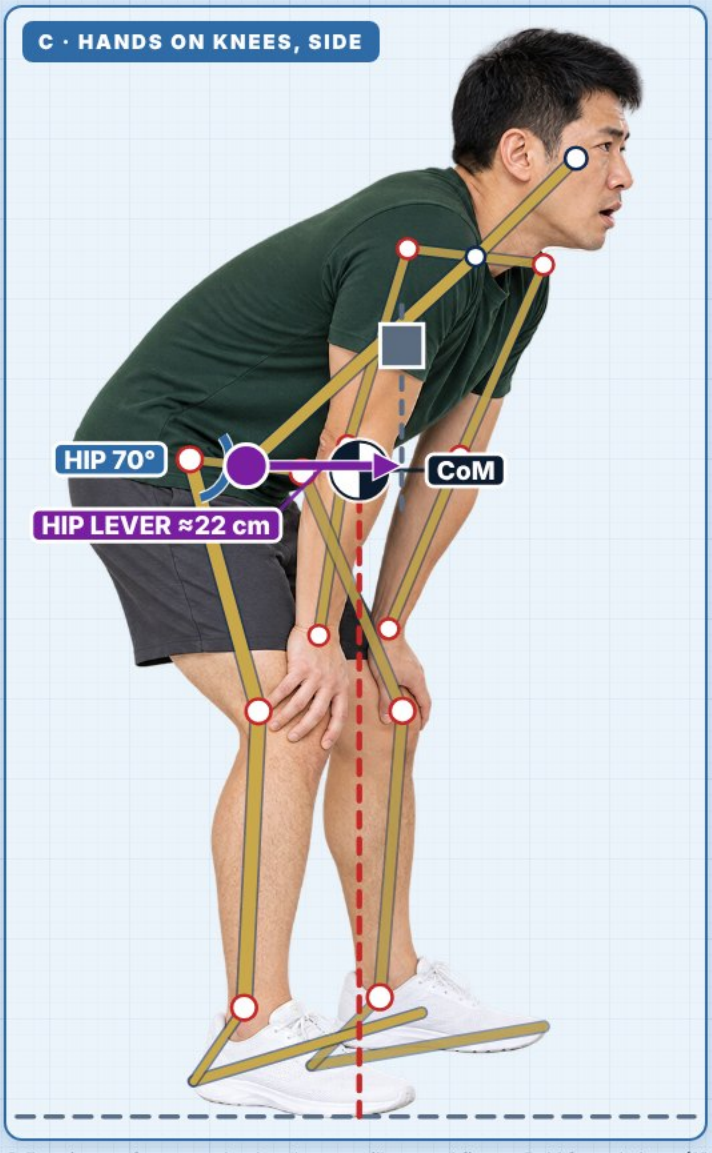
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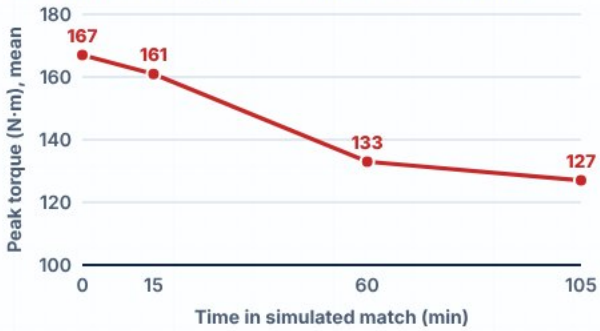
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Fatigue late in each half

- Bent over with hands on the knees, hips flexed about **70°**: the upper body sits **≈22 cm** in front of the hip, **≈91 N·m**, partly propped by the arms.
- In English professional football, 62% of hamstring strains occurred in matches, with an increase at the end of each half.

Eccentric strength fades across a match



10 professional players, isokinetic 300°/s; SD 25–35 N·m; concentric torque changed little. Greig (2008).

Key point: a fall of about 24% in eccentric strength by the end matches the late-half clustering of injuries (Woods et al., 2004).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Arm support not subtracted. Educational, not diagnostic.

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A · Backswing
Knee ≈94°

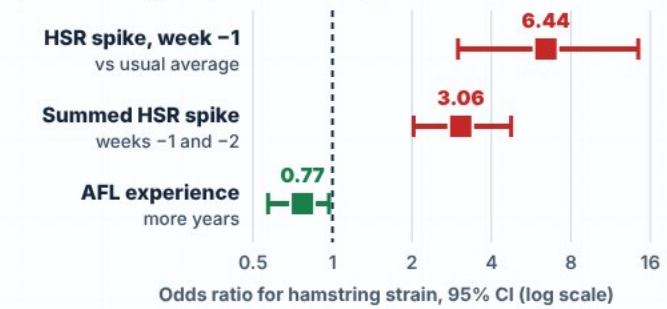


B · Follow-through
Hip ≈84°



C · Fatigued
≈91 N·m

Spikes in high-speed running raise risk



One Australian football team, two seasons; associations, not proof of cause. Duhig et al. (2016).

Decision pathway

1. **PREVENT**
   Include the Nordic exercise in a multi-component programme with high-speed running.
2. **PLAN LOAD**
   Keep regular sprint exposure and avoid large, rapid spikes above the usual weekly average.
3. **PREPARE**
   Train for late-match fatigue; after injury, progress and return by criteria.

NOT RECOMMENDED

Removing sprinting from training, then exposing players to sudden high-speed spikes in matches.

SEEK ASSESSMENT IF

Sudden pain at the back of the thigh during a sprint or kick with loss of function, a palpable gap, inability to walk, or pain high near the sitting bone after a high kick or slip.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Duhig, S., Shield, A. J., Opar, D., Gabbett, T. J., Ferguson, C., & Williams, M. (2016). Effect of high-speed running on hamstring strain injury risk. *British Journal of Sports Medicine, 50*(24), 1536–1540. https://doi.org/10.1136/bjsports-2015-095679

Ekstrand, J., Bengtsson, H., Waldén, M., Davison, M., Khan, K. M., & Hägglund, M. (2023). Hamstring injury rates have increased during recent seasons and now constitute 24% of all injuries in men's professional football: The UEFA Elite Club Injury Study from 2001/02 to 2021/22. *British Journal of Sports Medicine, 57*(5), 292–298. https://doi.org/10.1136/bjsports-2021-105407

Greig, M. (2008). The influence of soccer-specific fatigue on peak isokinetic torque production of the knee flexors and extensors. *The American Journal of Sports Medicine, 36*(7), 1403–1409. https://doi.org/10.1177/0363546508314413

Gronwald, T., Klein, C., Hoenig, T., Pietzonka, M., Bloch, H., Edouard, P., & Hollander, K. (2022). Hamstring injury patterns in professional male football (soccer): A systematic video analysis of 52 cases. *British Journal of Sports Medicine, 56*(3), 165–171. https://doi.org/10.1136/bjsports-2021-104769

Martin, R. L., Cibulka, M. T., Bolgla, L. A., Koc, T. A., Jr., Loudon, J. K., Manske, R. C., Weiss, L., Christoforetti, J. J., & Heiderscheit, B. C. (2022). Hamstring strain injury in athletes: Clinical practice guidelines. *Journal of Orthopaedic & Sports Physical Therapy, 52*(3), CPG1–CPG44. https://doi.org/10.2519/jospt.2022.0301

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

Woods, C., Hawkins, R. D., Maltby, S., Hulse, M., Thomas, A., & Hodson, A. (2004). The Football Association Medical Research Programme: An audit of injuries in professional football—analysis of hamstring injuries. *British Journal of Sports Medicine, 38*(1), 36–41.

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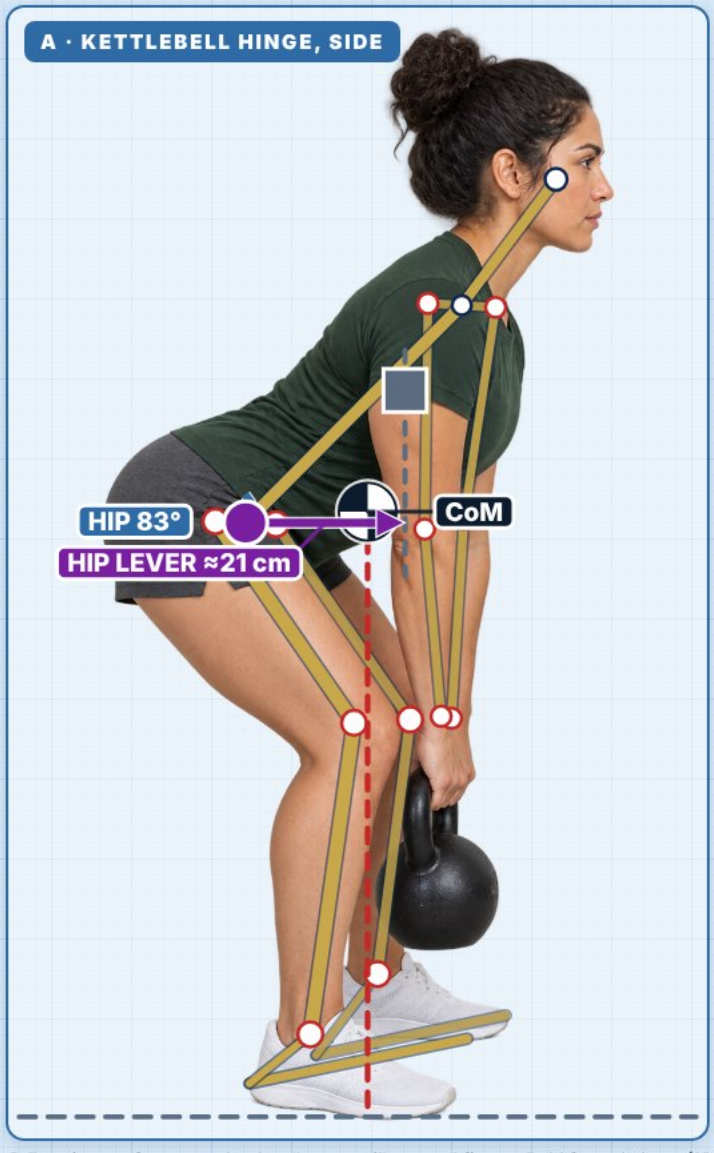
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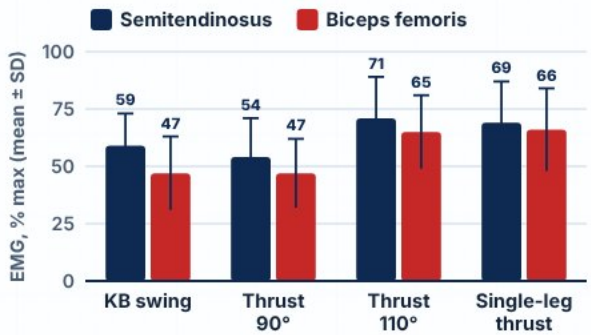
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The hinge: hamstrings as hip extensors

- Kettlebell deadlift with the hips back and the hip flexed about **83°**: the upper body acts **≈21 cm** in front of the hip, **≈85 N·m** before the bell.
- In the swing, the ballistic version of this hinge, semitendinosus was more active than biceps femoris; in hip thrusts the knee angle changed hamstring demand.

Hip-extension exercises, medial vs lateral



Female team handball players; peak normalised EMG. Sørensen et al. (2021).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Kettlebell load not included. Educational, not diagnostic.

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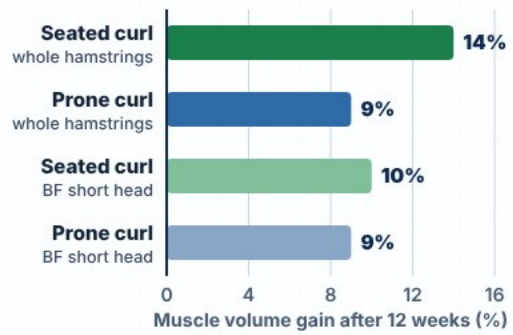
B · PRONE LEG CURL, SIDE



The curl: hamstrings as knee flexors

- Lying face down on a bench with an ankle weight, the right knee bent about **76°**: the hip is extended, so the two-joint hamstrings work at a short length.
- Training the same curl seated, with the hip flexed and the muscle longer, produced more hamstring growth than the prone version.

Longer length, more growth



20 adults, one leg seated and one prone, 70% 1RM, 5 × 10, twice weekly. Maeo et al. (2021).

Key point: both trained legs were similarly protected from damage after a later eccentric bout.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Lying pose: knee angle approximate; hip angle not reported. Educational, not diagnostic.

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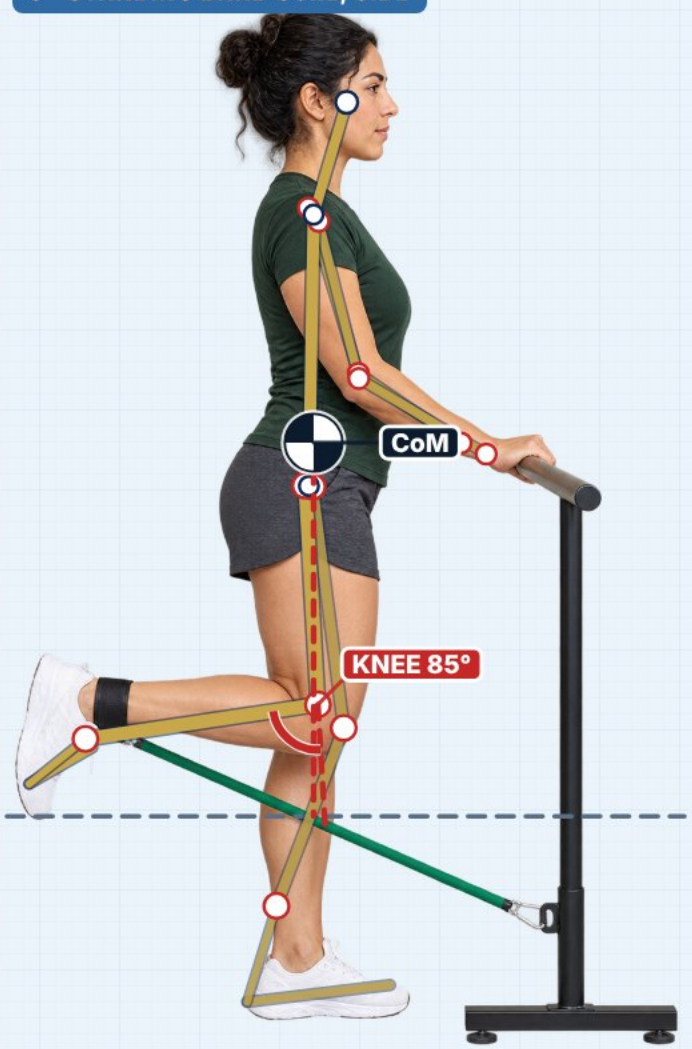
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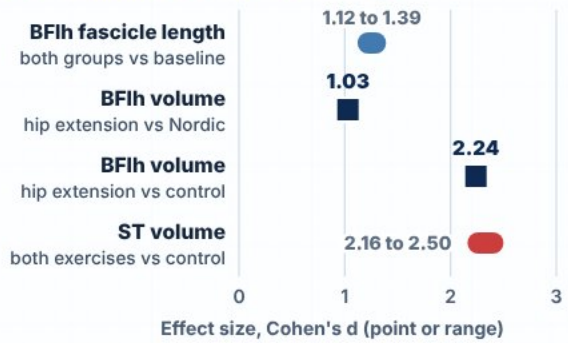
C · STANDING BAND CURL, SIDE



Both roles change the muscle

- Standing at a support, the right heel drawn towards the buttock against a band, knee bent about **85°**: a simple knee-flexion exercise.
- Over 10 weeks, 45° hip extension and the Nordic both lengthened biceps femoris long head fascicles; hip extension grew the long head more.

Hip extension vs Nordic training



30 recreationally active men, 10 weeks; fascicle change did not differ between exercises. Bourne et al. (2017).

Myth: "Leg curls are all you need." The hamstrings also extend the hip, and each exercise favours a different hamstring.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle of the curling (right) leg from pose landmarks in the side view. Educational, not diagnostic.

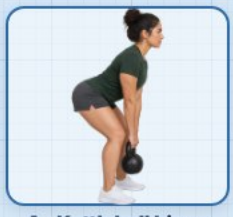
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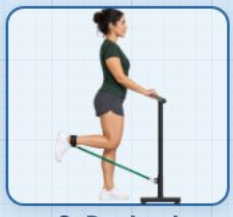
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A · Kettlebell hinge
≈85 N·m

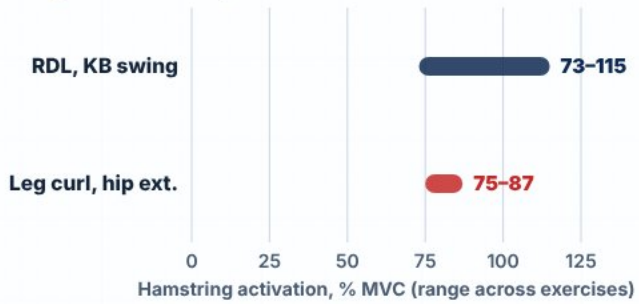


B · Prone curl
Knee ≈76°



C · Band curl
Knee ≈85°

Hinges favour ST; curls favour BF



Hinges: semitendinosus > biceps femoris by 17–22%; supine curl and hip extension: biceps femoris > semitendinosus by 20–23%. Zebis et al. (2013).

Decision pathway

1. **HINGE**
   Use deadlift-type hip extension to load the hamstrings at the hip.
2. **CURL**
   Add knee-flexion work, including the Nordic and seated curls with the hip flexed.
3. **COMBINE**
   Train both roles in prevention and, after injury, add eccentric work as tolerated.

NOT RECOMMENDED

Relying on one exercise type alone; heavy lengthened loading through sharp pain after a recent strain.

SEEK ASSESSMENT IF

Sudden sharp pain at the back of the thigh with loss of function, a palpable defect, extensive bruising, or pain near the sitting bone after a forceful movement.

REFERENCES (APA 7)

Bourne, M. N., Duhig, S. J., Timmins, R. G., Williams, M. D., Opar, D. A., Al Najjar, A., Kerr, G. K., & Shield, A. J. (2017). Impact of the Nordic hamstring and hip extension exercises on hamstring architecture and morphology: Implications for injury prevention. *British Journal of Sports Medicine, 51*(5), 469–477. https://doi.org/10.1136/bjsports-2016-096130

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Maeo, S., Huang, M., Wu, Y., Sakurai, H., Kusagawa, Y., Sugiyama, T., Kanehisa, H., & Isaka, T. (2021). Greater hamstrings muscle hypertrophy but similar damage protection after training at long versus short muscle lengths. *Medicine & Science in Sports & Exercise, 53*(4), 825–837. https://doi.org/10.1249/MSS.0000000000002523

Martin, R. L., Cibulka, M. T., Bolgla, L. A., Koc, T. A., Jr., Loudon, J. K., Manske, R. C., Weiss, L., Christoforetti, J. J., & Heiderscheit, B. C. (2022). Hamstring strain injury in athletes: Clinical practice guidelines. *Journal of Orthopaedic & Sports Physical Therapy, 52*(3), CPG1–CPG44. https://doi.org/10.2519/jospt.2022.0301

Sørensen, B., Aagaard, P., Malchow-Møller, L., Zebis, M. K., & Bencke, J. (2021). Medio-lateral hamstring muscle activity in unilateral vs. bilateral strength exercises in female team handball players: A cross-sectional study. *International Journal of Sports Physical Therapy, 16*(3), 704–714. https://doi.org/10.26603/001c.24150

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

Zebis, M. K., Skotte, J., Andersen, C. H., Mortensen, P., Petersen, H. H., Viskær, T. C., Jensen, T. L., Bencke, J., & Andersen, L. L. (2013). Kettlebell swing targets semitendinosus and supine leg curl targets biceps femoris: An EMG study with rehabilitation implications. *British Journal of Sports Medicine, 47*(18), 1192–1198. https://doi.org/10.1136/bjsports-2011-090281

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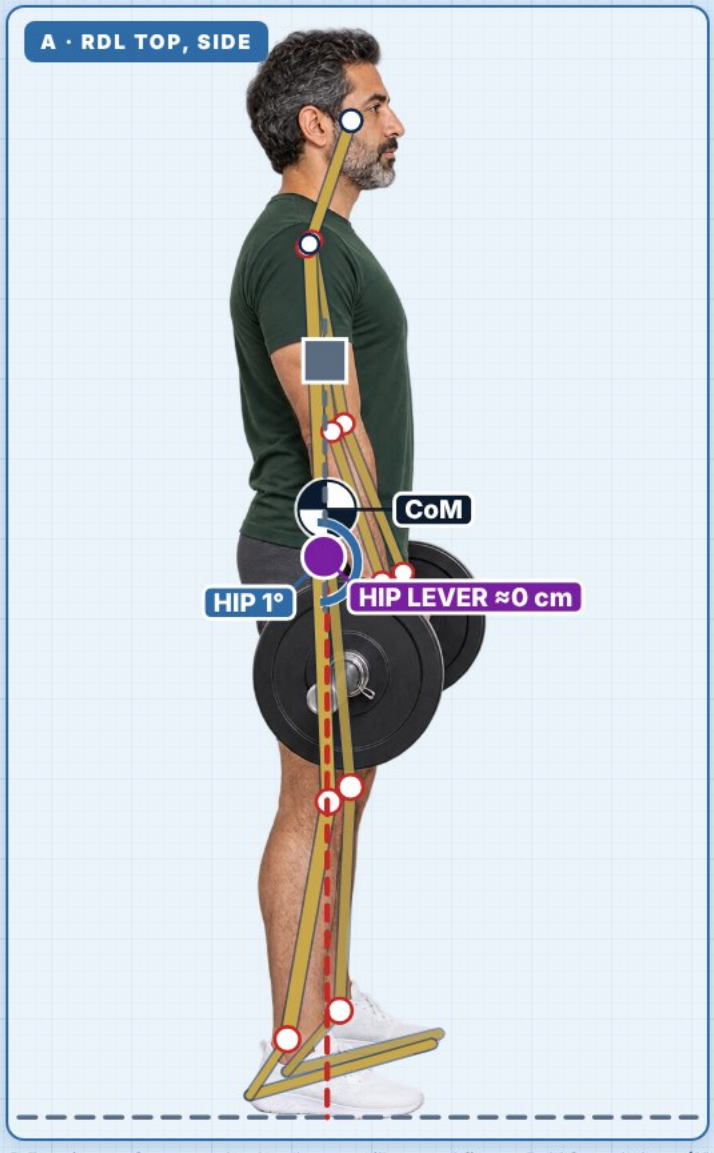
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INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

ROMANIAN DEADLIFT FOR HAMSTRINGS: LOADING THE HIP HINGE SAFELY

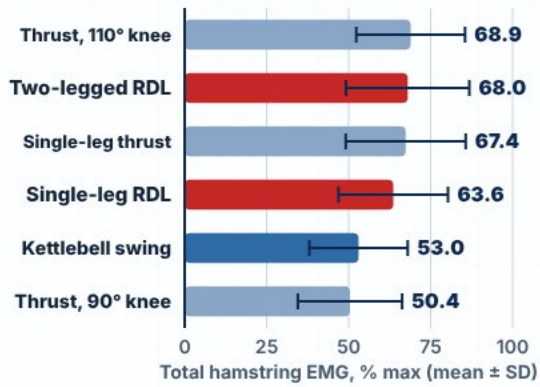
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Start tall, knees soft

- Standing tall with the bar at the thighs, hip near neutral (**1°**): the upper body sits almost over the hip (lever ≈**0 cm**), so hip-extensor demand is minimal.
- From here the hips move back with the spine neutral; the two-legged RDL matched the most demanding hip-thrust variant for total hamstring activity.

The RDL is a high-demand hamstring exercise



Female team handball players; peak normalised EMG. Sørensen et al. (2021).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Bar load not included. Educational, not diagnostic.

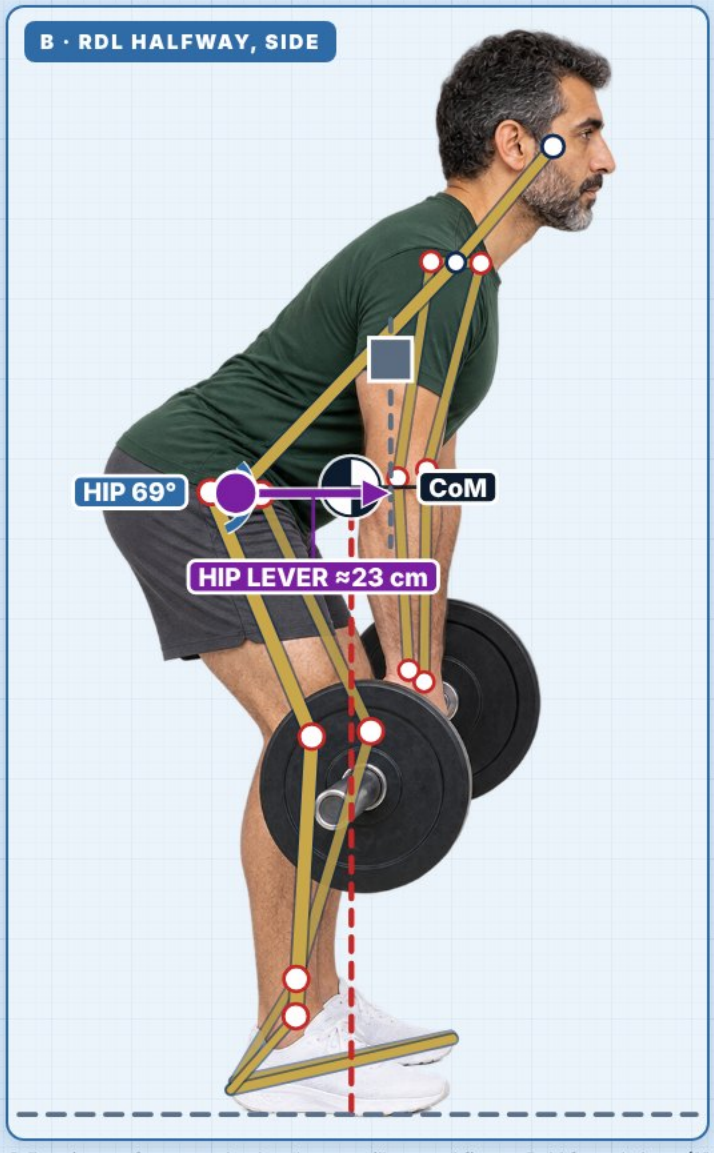
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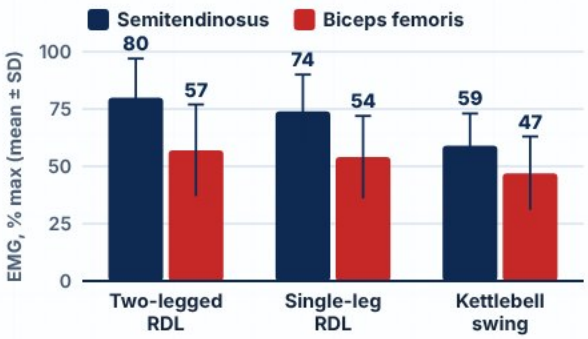
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Halfway: the lever grows

- Bar at knee height, hips back, back flat and knees slightly bent: hip flexion ≈**69°**, hip lever ≈**23 cm**, hip moment ≈**96 N·m** from the upper body alone.
- The RDL favoured the medial hamstrings: semitendinosus exceeded biceps femoris by 20–24 percentage points, so pair it with exercises that load biceps femoris.

Medial hamstrings lead in the RDL



Same cohort; RDL and swing favoured the medial hamstrings ($p < 0.01$). Sørensen et al. (2021).

Myth: "The RDL is a lower-back exercise." Semitendinosus reached 80% and biceps femoris 57% of maximal activity.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Bar load not included. Educational, not diagnostic.

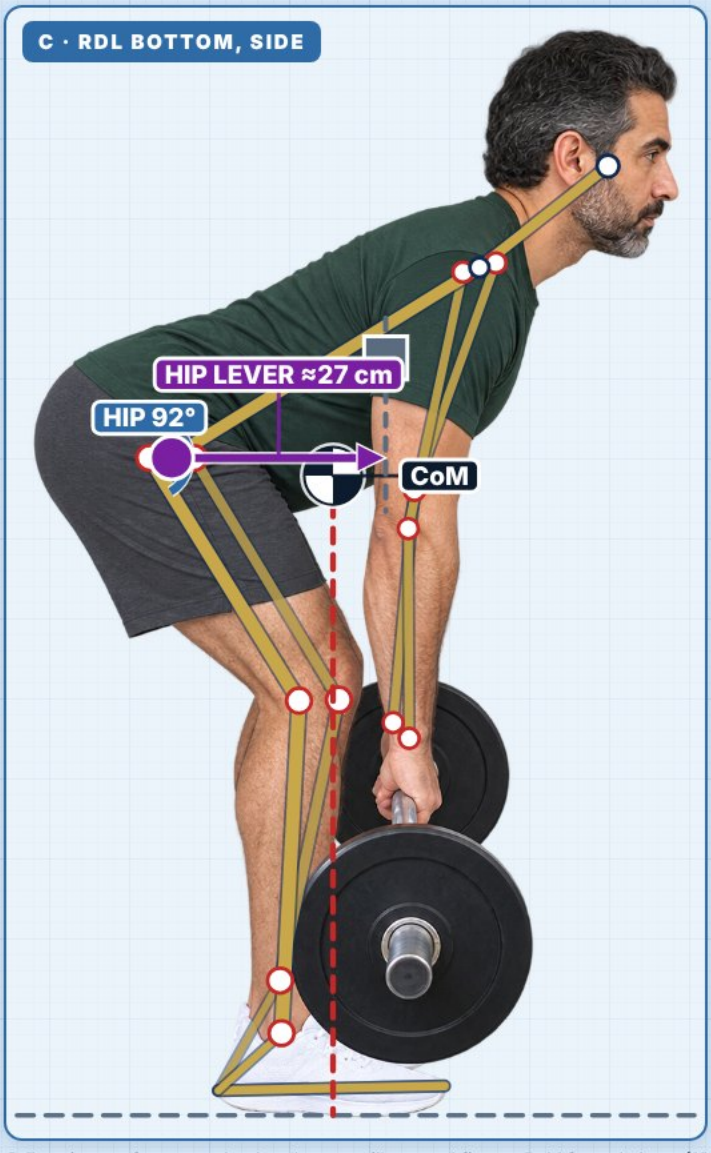
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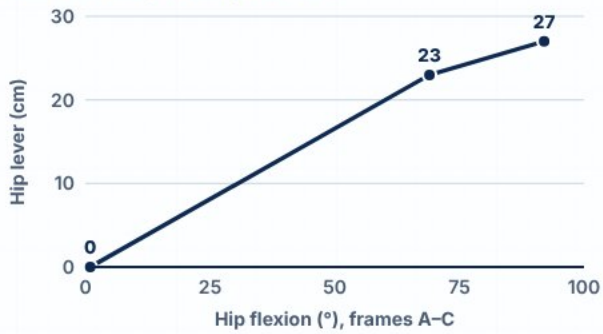
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Bottom: longest muscle, largest lever

- Bar at mid-shin, trunk close to horizontal, back flat: hip flexion ≈**92°**, hip lever ≈**27 cm**, hip moment ≈**111 N·m** before the bar is added.
- This is where the hamstrings work longest; lower only as far as the back stays flat and add range or load gradually.

Deeper hinge, longer lever



Measured in frames A–C of this plate; upper body only, bar load excluded.

Key point: two-legged and single-leg RDLs gave similar hamstring activity (68.0% vs 63.6% of max), so single-leg work is an option (Sørensen et al., 2021).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Bar load not included. Educational, not diagnostic.

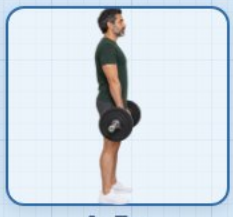
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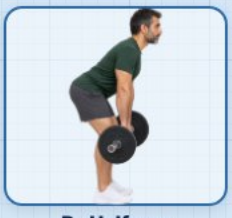
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A · Top
Lever ≈0 cm

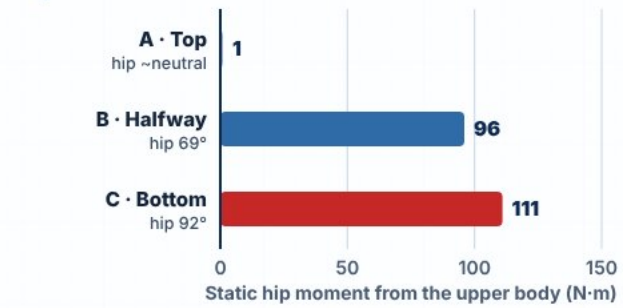


B · Halfway
≈96 N·m



C · Bottom
≈111 N·m

Depth is the dose



Measured in frames A–C of this plate; 70 kg adult, bar load excluded.
Lengthening rehab: 28 vs 51 days to return (Askling et al., 2013).

Decision pathway

1. **HINGE WELL**
   Push the hips back with soft knees and a flat back; lower only as far as that holds.
2. **PROGRESS**
   Add load, range and single-leg work gradually, within a programme that includes the Nordic.
3. **BALANCE**
   Pair the RDL with knee-flexion work that biases biceps femoris.

NOT RECOMMENDED

Rounding the back to reach the floor; heavy RDLs through sharp thigh pain after a recent strain.

SEEK ASSESSMENT IF

A sudden pop or sharp pain while lowering, pain at the sitting bone, back pain spreading down the leg with numbness, or saddle numbness or bladder or bowel change (emergency).

REFERENCES (APA 7)

Askling, C. M., Tengvar, M., & Thorstensson, A. (2013). Acute hamstring injuries in Swedish elite football: A prospective randomised controlled clinical trial comparing two rehabilitation protocols. *British Journal of Sports Medicine, 47*(15), 953–959. https://doi.org/10.1136/bjsports-2013-092165

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Sørensen, B., Aagaard, P., Malchow-Møller, L., Zebis, M. K., & Bencke, J. (2021). Medio-lateral hamstring muscle activity in unilateral vs. bilateral strength exercises in female team handball players: A cross-sectional study. *International Journal of Sports Physical Therapy, 16*(3), 704–714. https://doi.org/10.26603/001c.24150

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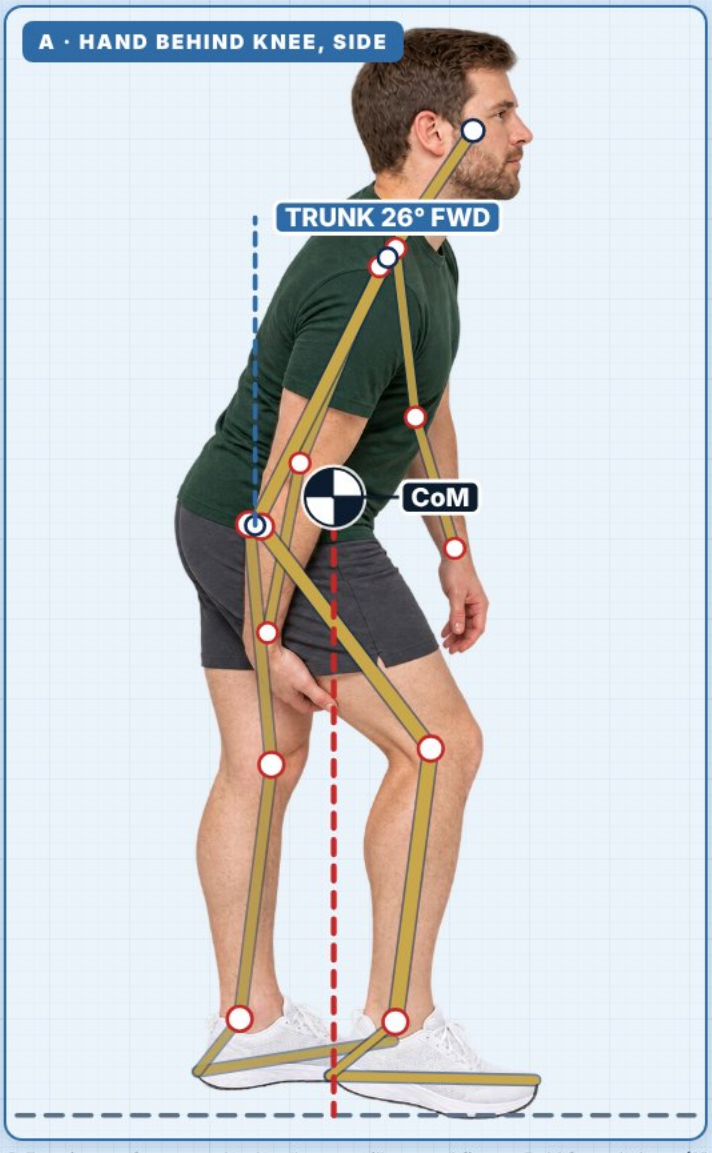
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HAMSTRING PAIN BEHIND THE KNEE: TENDON, NERVE OR KNEE JOINT?

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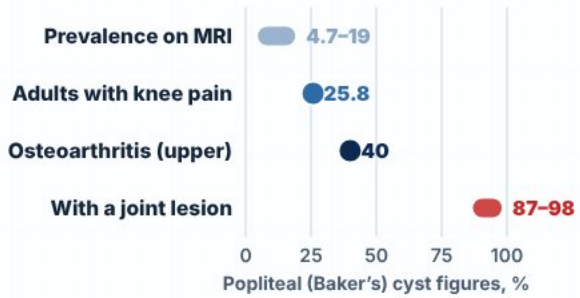


2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line from hip to shoulder points in the side view. Educational, not diagnostic.

One small area, three possible sources

- Hand on the back of the knee, trunk **26°** forward: this area holds the distal hamstring tendons (biceps femoris laterally, semitendinosus and semimembranosus medially), the joint and the sciatic nerve branches.
- A popliteal (Baker's) cyst is common, and on MRI 87–98% sit alongside an intra-articular lesion, so a swelling here usually points to the joint rather than the hamstring.

Cysts usually signal a joint problem



Narrative review compiling MRI and radiological studies; bars are ranges across studies. Sharafatvaziri et al. (2026).

Myth: "Pain behind the knee is always a tight hamstring." Most hamstring strains sit proximally; the joint and the nerve are other possible sources.

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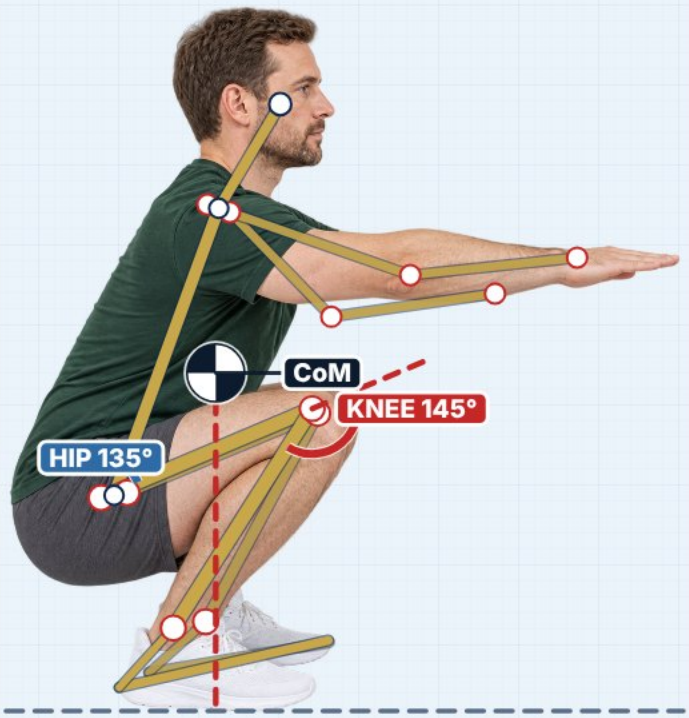
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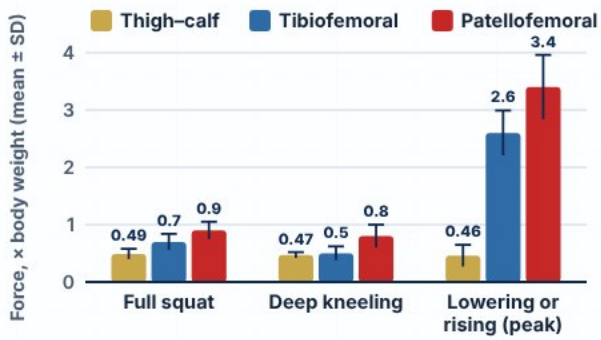
B · DEEP SQUAT, SIDE



Deep flexion presses on the back of the knee

- Deep squat with the knee flexed **145°** and the hip **135°**: thigh and calf press together, and in a modelled full squat this contact carried about half of body weight.
- Peak joint forces occurred while lowering and rising, not at the bottom. Firm compression behind the knee can still provoke a cyst, a meniscal problem or distal tendon pain.

Contact unloads the joint at the bottom



13 men; full squat 156 ± 6° knee flexion; model estimates. Glitsch et al. (2022).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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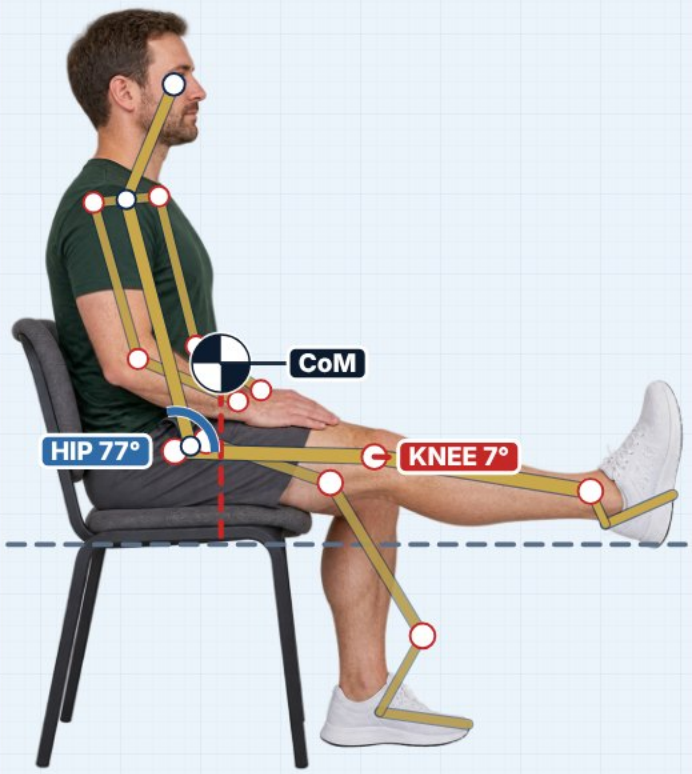
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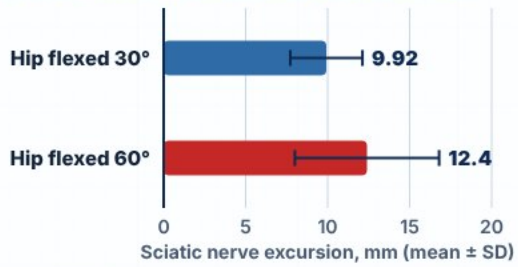
C · KNEE EXTENSION, SIDE



Straightening the knee slides the nerve

- Sitting with the hip flexed **77°** and the knee straightened to **7°**: this lengthens both the hamstrings and the sciatic nerve bed behind the thigh and knee.
- In 16 adults the nerve slid about 10–12 mm, more with the hip bent further. Pain that changes with hip or neck position suggests a nerve contribution.

More hip flexion, more nerve movement



Ultrasound in 16 asymptomatic adults, knee extended 90°→0°; p = 0.02. Ridehalgh et al. (2014).

Key point: tenderness that is maximal at the tendon insertion suggests tendon pathology; a swelling suggests the joint; position-dependent pain suggests the nerve.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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A · Hand behind knee
Trunk 26° forward

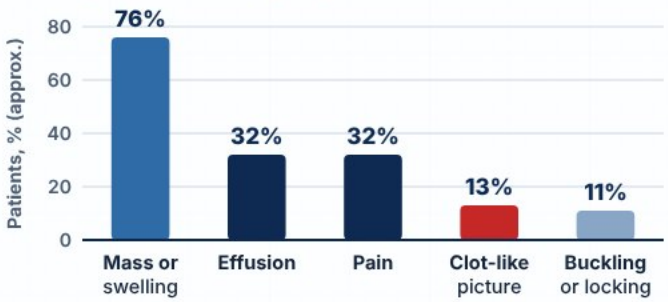


B · Deep squat
Knee 145°



C · Knee extension
Knee 7°

How symptomatic cysts present



Approximate % from an observational cohort summarised in a narrative review. Sharafatvaziri et al. (2026).

Decision pathway

1. **LOCATE**
   Find where tenderness is greatest: at the tendon insertion, in a swelling, or nowhere specific.
2. **DIFFERENTIATE**
   Check whether hip or neck position changes the pain; if it does, consider the nerve or the lumbar spine.
3. **MATCH**
   Load a sore tendon progressively, have the knee joint behind a cyst assessed, and use gentle nerve glides for nerve signs.

NOT RECOMMENDED

Stretching harder into pain behind the knee before the source is known; repeated deep squats that provoke a swollen knee.

SEEK ASSESSMENT IF

The calf or back of the knee is swollen, warm or tender, the knee locks or gives way, it swells markedly after injury, or numbness spreads down the leg.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Glitsch, U., Heinrich, K., & Ellegast, R. P. (2022). Estimation of tibiofemoral and patellofemoral joint forces during squatting and kneeling. *Applied Sciences, 12*(1), 255. https://doi.org/10.3390/app12010255

Martin, R. L., Cibulka, M. T., Bolgla, L. A., Koc, T. A., Jr., Loudon, J. K., Manske, R. C., Weiss, L., Christoforetti, J. J., & Heiderscheit, B. C. (2022). Hamstring strain injury in athletes: Clinical practice guidelines. *Journal of Orthopaedic & Sports Physical Therapy, 52*(3), CPG1–CPG44. https://doi.org/10.2519/jospt.2022.0301

Ridehalgh, C., Moore, A., & Hough, A. (2014). Normative sciatic nerve excursion during a modified straight leg raise test. *Manual Therapy, 19*(1), 59–64.

Sharafatvaziri, A., Farahmand, Y., Vosoughi, F., Moezi, M., & Soleymani, M. (2026). Popliteal cyst: Etiology, diagnosis and management, a current concept review. *The Archives of Bone and Joint Surgery, 14*(9), 578–586. https://doi.org/10.22038/ABJS.2026.88487.4021

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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SCIATIC NERVE SENSITIVITY: WHEN "TIGHT HAMSTRINGS" IS A NERVE SIGN

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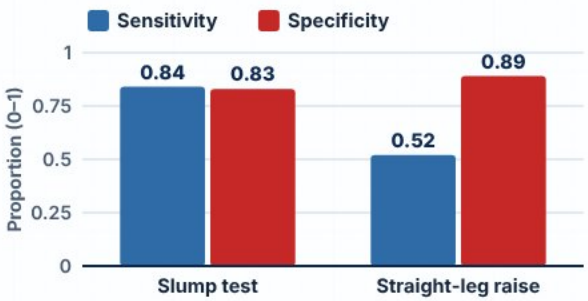
A · SLUMP SITTING, SIDE



Slumping loads the nerve, not just muscle

- Back slumped, chin to chest and the knee straightening (**38°** flexion here): each part adds tension along the sciatic nerve tract, so posterior thigh "tightness" may be neural.
- The key step is structural differentiation: neck movement changes nerve load without changing hamstring length, so symptoms that change with the head point to the nerve.

Slump detected more disc cases



75 patients, 38 with MRI-confirmed lumbar disc herniation and 37 controls. Majlesi et al. (2008).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle from pose landmarks in the side view. Educational, not diagnostic.

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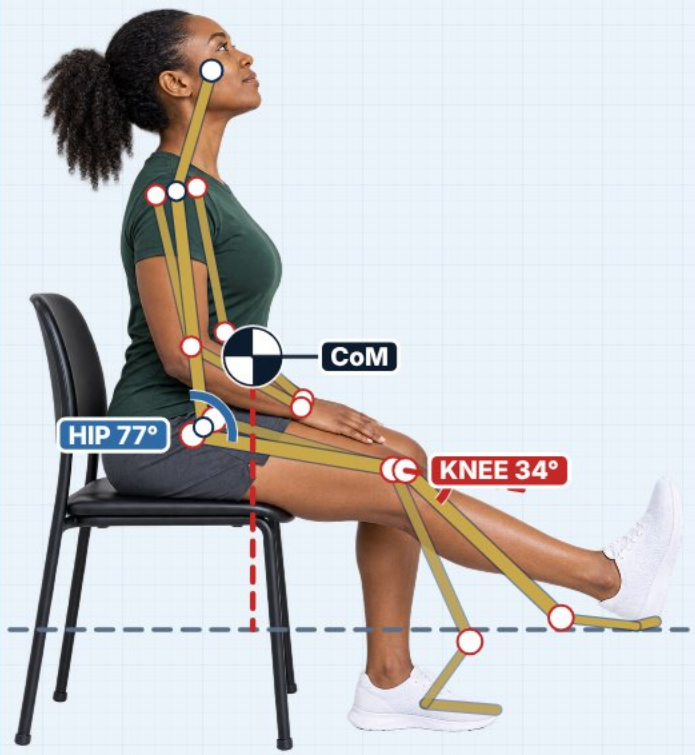
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B · NERVE GLIDE, SIDE



Look up as the knee straightens: a slider

- Upright sitting, hip flexed **77°**, looking up while the knee straightens to **34°** and the toes pull up: neck extension eases nerve tension at one end as the leg adds it.
- In 31 healthy adults this slider moved the nerve most (3.2 mm), more than a tensioner (2.6 mm); neck flexion alone barely moved it at the thigh.

Sliders move the nerve most



Ultrasound in the posterior thigh, 31 healthy participants; slider vs tensioner P = .002. Ellis et al. (2012).

Key point: when the nerve is irritable, sliders give movement with less tension than tensioners.

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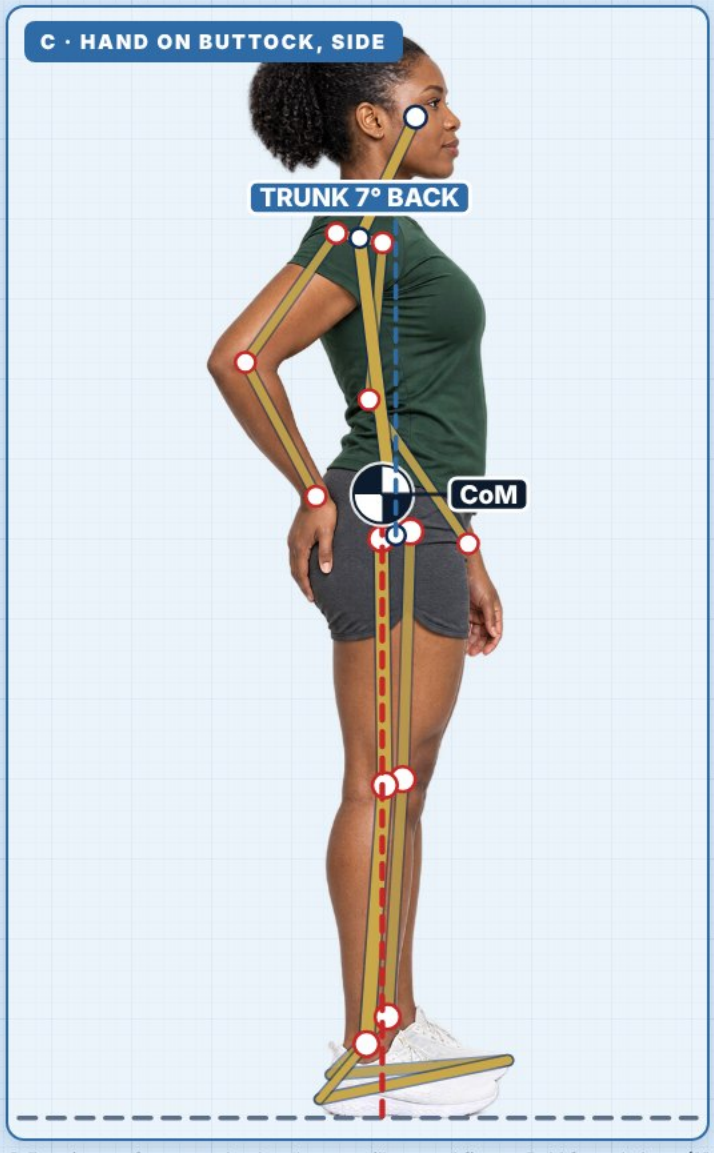
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INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

SCIATIC NERVE SENSITIVITY: WHEN "TIGHT HAMSTRINGS" IS A NERVE SIGN

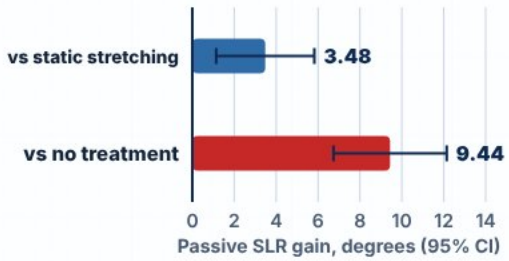
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Buttock-to-thigh pain: look upstream

- Standing with a hand on the buttock and the trunk **7°** back: insidious, vague pain spreading from here into the posterior thigh should raise the possibility of referral from the lumbar spine.
- Deep gluteal syndrome with nerve entrapment and ischial tunnel syndrome are also in the guideline's differential for posterior thigh pain.

Nerve techniques: modest range gains



Neurodynamic treatment, pooled mean difference; 30 RCTs, 1379 participants. Bertacchini et al. (2025).

Myth: "A tight thigh just needs harder stretching." If neck or ankle position changes the symptoms, the nerve is involved, and aggressive static stretching adds tension to it.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line from hip to shoulder points in the side view. Educational, not diagnostic.

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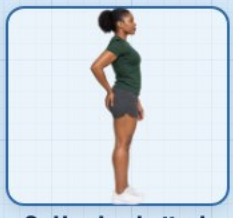
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A · Slump sitting
Knee 38°



B · Nerve glide
Slider



C · Hand on buttock
Trunk 7° back

Small differences between methods



Pooled RCT data; all differences are within the 13° measurement error of the SLR (Martin et al., 2022). Bertacchini et al. (2025).

Decision pathway

1. **DIFFERENTIATE**
   Change neck or ankle position: if the thigh symptoms change, treat the nerve as a contributor.
2. **GLIDE**
   Start with sliders (look up as the knee straightens) when the nerve is irritable.
3. **PROGRESS**
   Add tensioners as tolerated and expect modest range gains rather than dramatic ones.

NOT RECOMMENDED

Aggressive static stretching into burning, tingling or pain that changes with neck or ankle position.

SEEK ASSESSMENT IF

Leg weakness that is getting worse, numbness in the saddle area or a change in bladder or bowel control (urgent), or vague, spreading pain from the back.

REFERENCES (APA 7)

Bertacchini, P., Gaucci, M., & Contri, A. (2025). Effectiveness of neurodynamic treatment on hamstring flexibility: A systematic review and meta-analysis of randomized controlled trials. Journal of Back and Musculoskeletal Rehabilitation. https://doi.org/10.1177/10538127251372333

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Ellis, R. F., Hing, W. A., & McNair, P. J. (2012). Comparison of longitudinal sciatic nerve movement with different mobilization exercises: An in vivo study utilizing ultrasound imaging. *Journal of Orthopaedic & Sports Physical Therapy, 42*(8), 667–675. https://doi.org/10.2519/jospt.2012.3854

Majlesi, J., Togay, H., Unalan, H., & Toprak, S. (2008). The sensitivity and specificity of the slump and the straight leg raising tests in patients with lumbar disc herniation. *Journal of Clinical Rheumatology, 14*(2), 87–91. https://doi.org/10.1097/RHU.0b013e31816b2f99

Martin, R. L., Cibulka, M. T., Bolgla, L. A., Koc, T. A., Jr., Loudon, J. K., Manske, R. C., Weiss, L., Christoforetti, J. J., & Heiderscheit, B. C. (2022). Hamstring strain injury in athletes: Clinical practice guidelines. *Journal of Orthopaedic & Sports Physical Therapy, 52*(3), CPG1–CPG44. https://doi.org/10.2519/jospt.2022.0301

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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SLUMP AND STRAIGHT-LEG RAISE TESTS: WHAT THEY TELL YOU ABOUT THE NERVE

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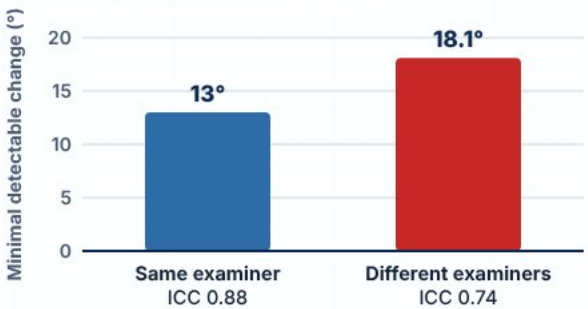
A · STRAIGHT-LEG RAISE, SIDE



The SLR: a length test and a nerve test

- Lying on the back with one leg lifted, knee straight, the other leg flat: the raise lengthens the hamstrings and tensions the sciatic nerve and lumbosacral nerve roots together.
- The angle is not very precise: a change smaller than about 13° (same examiner) or 18° (different examiners) may be measurement error rather than real progress.

The error band of the SLR angle



SLR measured with an inclinometer; guideline Table 9, citing primary studies. Martin et al. (2022).

Myth: "A positive SLR proves a disc problem." Its pooled specificity is only 0.28; the crossed SLR is far more specific (0.90).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No angles are measured on the lying image: pose landmarks are unreliable when lying. Educational, not diagnostic.

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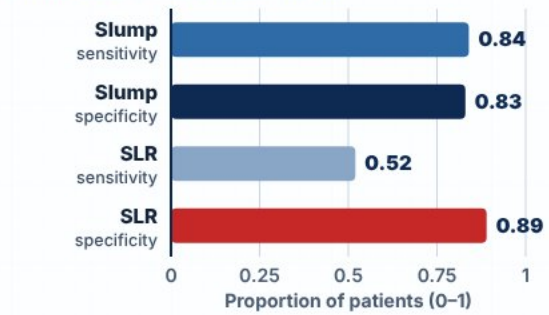
B · SLUMP TEST, SIDE



Slump: tension built from the spine down

- Trunk slumped, chin down, hip flexed **84°** and knee extended to **18°** with the foot pulled up: spine, hip, knee and ankle each add load along the nerve tract.
- In 75 patients the slump test detected more MRI-confirmed disc herniations than the SLR (sensitivity 0.84 vs 0.52), with similar specificity.

Slump vs SLR in one sample



38 patients with MRI-confirmed lumbar disc herniation, 37 controls. Majlesi et al. (2008).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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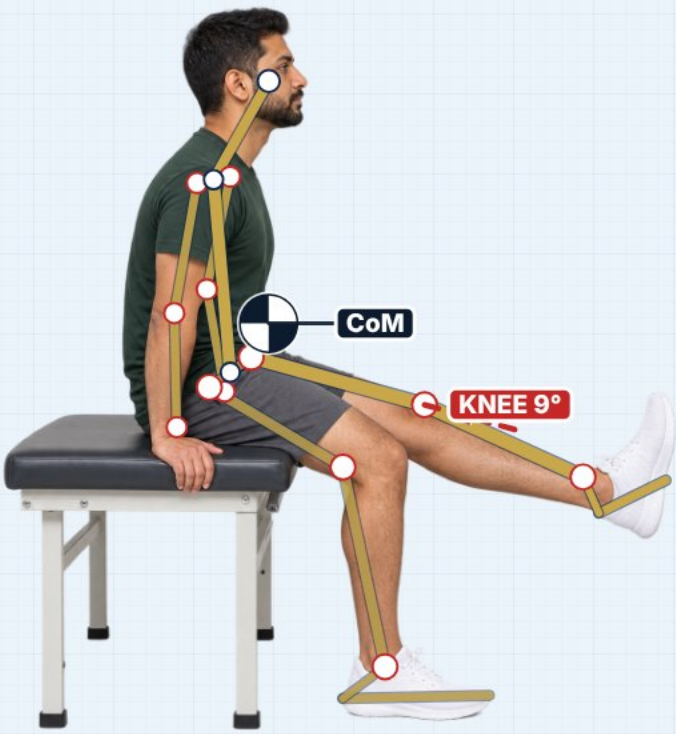
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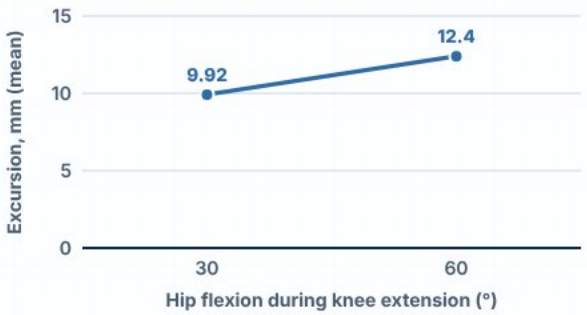
C · SLUMP, HEAD UP, SIDE



Lifting the head: the differentiation step

- The same slump with the head lifted to look forward and the knee at **9°**: knee position and hamstring length stay the same, so a change in symptoms implicates the nerve.
- Bending the hip further increased nerve slide during knee straightening, which is why the slumped start pre-tensions the nerve before the knee moves.

More hip flexion, more nerve slide



16 asymptomatic adults, ultrasound; SD 2.2 and 4.4 mm; p = 0.02. Ridehalgh et al. (2014).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle of the straight leg from pose landmarks in the side view. Educational, not diagnostic.

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A · Straight-leg raise
Lying, knee straight

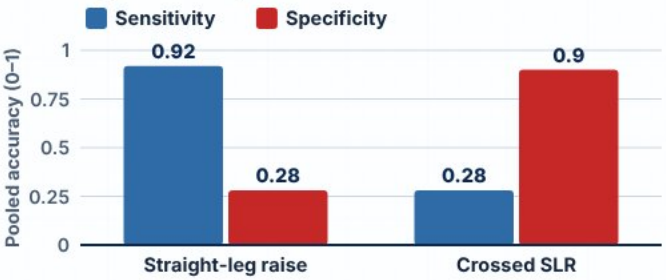


B · Slump test
Hip 84°



C · Slump, head up
Differentiation

SLR helps rule out; crossed SLR rules in



Disc herniation with radiculopathy, mainly surgical samples; 95% CI sensitivity 0.87–0.95, specificity 0.18–0.40 (SLR). van der Windt et al. (2010).

Decision pathway

1. **SCREEN**
   Use the SLR and slump test within a lumbar and neurological screen, read with their accuracy in mind.
2. **DIFFERENTIATE**
   Reproduce the leg symptoms, then move a distant joint (head or ankle) to see whether they change.
3. **MEASURE**
   Track hamstring length as the knee extension deficit with the hip at 90°, using an inclinometer.

NOT RECOMMENDED

Treating a positive SLR as proof of a disc problem; reading small angle changes as real progress.

SEEK ASSESSMENT IF

Leg weakness that is getting worse, saddle-area numbness or a change in bladder or bowel control (urgent), or spreading leg pain with numbness.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Majlesi, J., Togay, H., Unalan, H., & Toprak, S. (2008). The sensitivity and specificity of the slump and the straight leg raising tests in patients with lumbar disc herniation. *Journal of Clinical Rheumatology, 14*(2), 87–91. https://doi.org/10.1097/RHU.0b013e31816b2f99

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Ridehalgh, C., Moore, A., & Hough, A. (2014). Normative sciatic nerve excursion during a modified straight leg raise test. *Manual Therapy, 19*(1), 59–64.

van der Windt, D. A. W. M., Simons, E., Riphagen, I. I., Ammendolia, C., Verhagen, A. P., Laslett, M., Devillé, W., Deyo, R. A., Bouter, L. M., de Vet, H. C. W., & Aertgeerts, B. (2010). Physical examination for lumbar radiculopathy due to disc herniation in patients with low-back pain. *Cochrane Database of Systematic Reviews, 2010*(2), Article CD007431. https://doi.org/10.1002/14651858.CD007431.pub2

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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HAMSTRING CRAMPS: FATIGUE, HYDRATION AND WHAT THE EVIDENCE SUPPORTS

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A · THIGH CRAMP, SIDE



A cramp grips; a strain lingers

- Sitting on the floor, gripping the back of the thigh with the knee bent: a cramp is a sudden, painful, involuntary muscle contraction during or soon after exercise.
- Posterior thigh cramping can also accompany a grade I strain, so pain, bruising or weakness that persists after the "cramp" suggests a strain instead.

About one in five cramped



43 of 209 analysed; previous cramps and a faster race time were the independent risk factors. Schwellnus et al. (2011).

Key point: a history of cramping and racing faster than usual predicted cramps; fluid and electrolyte measures did not.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No overlay or angles on this image: pose landmarks are unreliable for this floor-sitting pose. Educational, not diagnostic.

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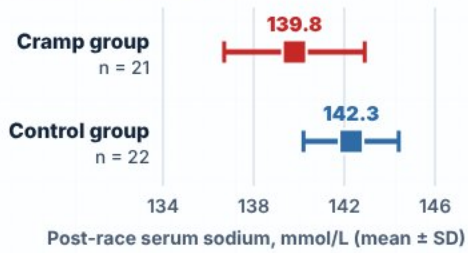
B · DRINKING WATER, SIDE



Hydration did not separate crampers

- Standing upright (trunk **4°** back) drinking water: sensible for comfort and safety, but in endurance cohorts crampers were not more dehydrated than non-crampers.
- In ultra-distance runners, body-weight and plasma-volume changes did not differ. Sodium was slightly lower in crampers, a small gap that does not support simple salt loss.

Serum sodium: a small gap



Immediately post-race; p = 0.004; magnesium was slightly higher in crampers. Schwellnus et al. (2004).

Myth: "Cramps are caused by dehydration and low salt." Crampers did not differ in body-weight change; pace and previous cramps predicted them.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line from hip to shoulder points in the side view. Educational, not diagnostic.

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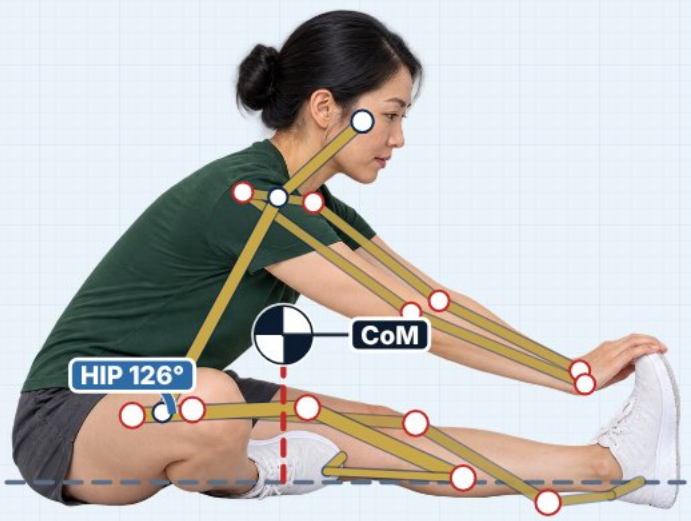
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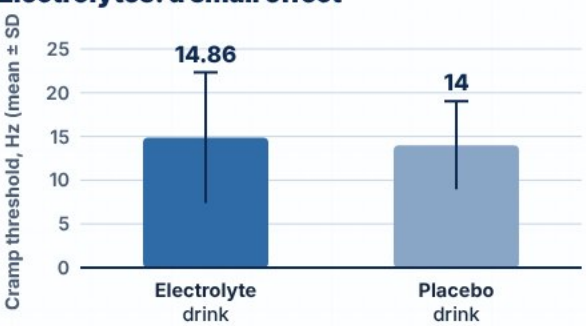
C · LONG-SIT STRETCH, SIDE



Gentle stretch for acute relief

- Long sitting, reaching towards the foot with the hip flexed **126°** and the other knee bent: stopping and gently stretching the cramping muscle is the practical first step.
- In a laboratory test, an electrolyte drink raised the cramp threshold only slightly, so electrolytes may play a minor role but do not explain most cramps.

Electrolytes: a small effect



Electrically induced cramps, electrolyte vs placebo beverage; P = .038. Earp et al. (2019).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip angle from pose landmarks in the side view. Educational, not diagnostic.

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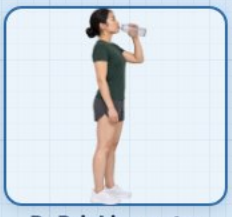
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A · Thigh cramp
Sudden, involuntary

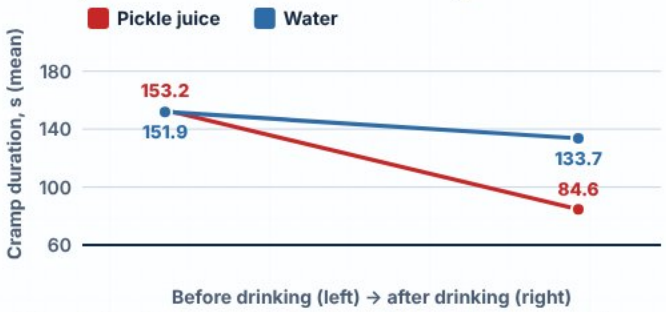


B · Drinking water
Comfort and safety



C · Long-sit stretch
Hip 126°

Cramps eased before sodium changed



10 hypohydrated men; ~1 ml/kg pickle juice shortened cramps by 49.1 s vs water while plasma sodium barely changed. Miller et al. (2010).

Decision pathway

1. **RELIEVE**
   Stop and gently stretch the cramping muscle; a strong-tasting stimulus may shorten a cramp through a reflex.
2. **PREVENT**
   Pace sensibly and build fatigue resistance: previous cramps and going faster than usual were the strongest predictors.
3. **HYDRATE**
   Drink for comfort and safety, not as a cramp cure; extra fluid or salt alone is not supported.

NOT RECOMMENDED

Relying on extra salt or fluid alone to prevent cramps; forcing hard stretches through a suspected strain.

SEEK ASSESSMENT IF

Cramps with dark urine, severe or prolonged muscle pain or swelling, confusion, widespread cramping in the heat, or pain and bruising that persist.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Earp, J. E., Stearns, R. L., Stranieri, A., Agostinucci, J., Lepley, A. S., Matson, T., & Ward-Ritacco, C. L. (2019). Electrolyte beverage consumption alters electrically induced cramping threshold. *Muscle & Nerve, 60*(5), 598–603. https://doi.org/10.1002/mus.26650

Martin, R. L., Cibulka, M. T., Bolgla, L. A., Koc, T. A., Jr., Loudon, J. K., Manske, R. C., Weiss, L., Christoforetti, J. J., & Heiderscheit, B. C. (2022). Hamstring strain injury in athletes: Clinical practice guidelines. *Journal of Orthopaedic & Sports Physical Therapy, 52*(3), CPG1–CPG44. https://doi.org/10.2519/jospt.2022.0301

Miller, K. C., Mack, G. W., Knight, K. L., Hopkins, J. T., Draper, D. O., Fields, P. J., & Hunter, I. (2010). Reflex inhibition of electrically induced muscle cramps in hypohydrated humans. *Medicine & Science in Sports & Exercise, 42*(5), 953–961. https://doi.org/10.1249/MSS.0b013e3181c0647e

Schwellnus, M. P., Drew, N., & Collins, M. (2011). Increased running speed and previous cramps rather than dehydration or serum sodium changes predict exercise-associated muscle cramping: A prospective cohort study in 210 Ironman triathletes. *British Journal of Sports Medicine, 45*(8), 650–656.

Schwellnus, M. P., Nicol, J., Laubscher, R., & Noakes, T. D. (2004). Serum electrolyte concentrations and hydration status are not associated with exercise associated muscle cramping (EAMC) in distance runners. *British Journal of Sports Medicine, 38*(4), 488–492.

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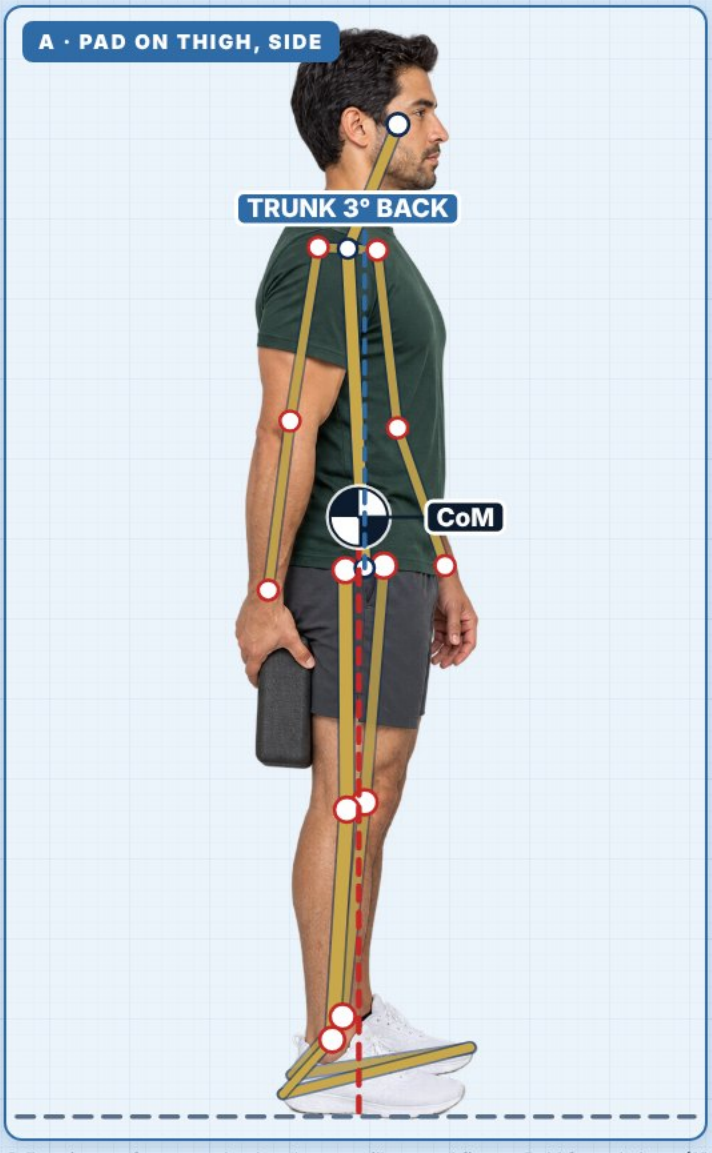
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HAMSTRING MUSCLE BRUISE VERSUS STRAIN: TELLING THEM APART

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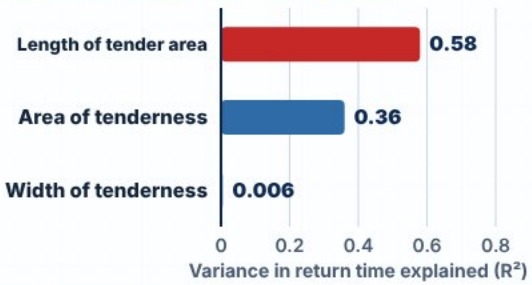


2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line from hip to shoulder points in the side view. Educational, not diagnostic.

Mechanism first: a blow or a stretch?

- Standing upright (trunk **3°** back), holding a foam pad at the back of the thigh to mark an impact area: a direct blow here suggests a contusion, not a strain.
- In English professional rugby, thigh haematomas were the most common injury, while hamstring injuries in backs caused the most days of absence.

Palpation relates to recovery time



Strains; guideline text citing a primary study; width P = .75 (not significant). Martin et al. (2022).

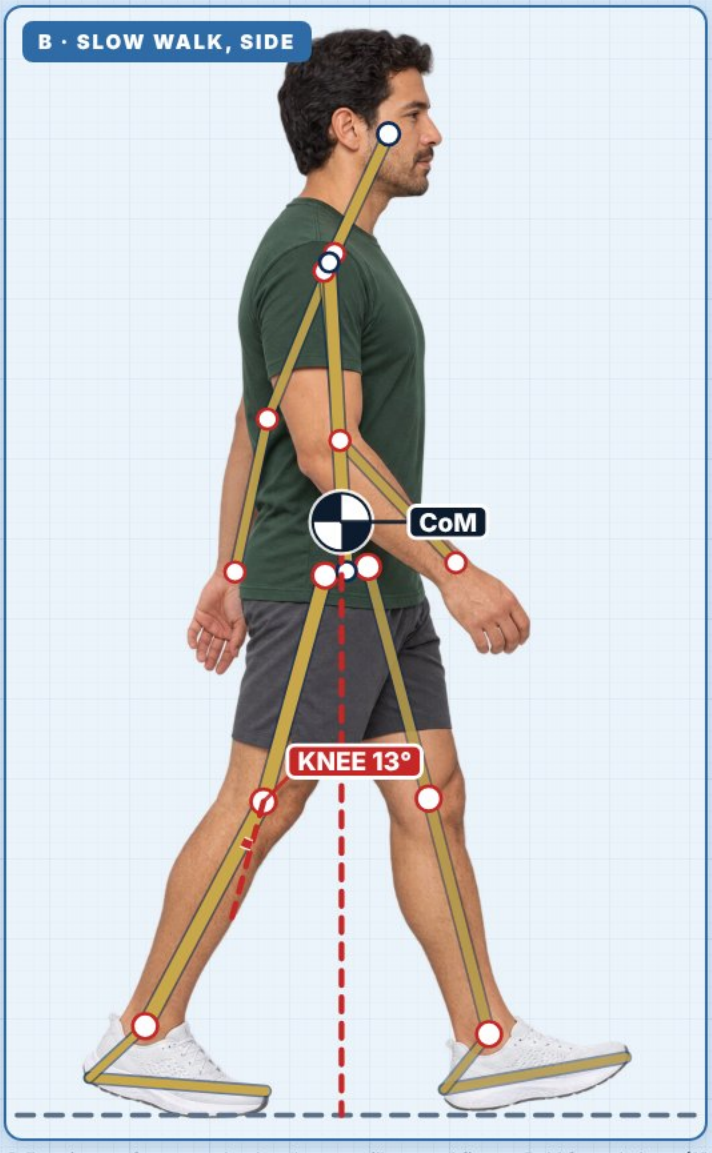
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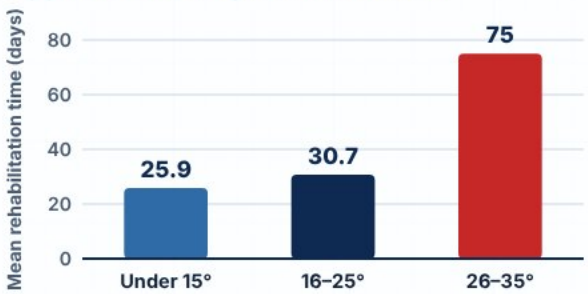
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A short, guarded stride

- Walking slowly with a shortened stride, trailing knee flexed **13°**: sudden pain while sprinting or stretching, then pain on stretch or contraction and lost function, points to a strain.
- A larger active knee extension deficit with the hip at 90° was linked with longer rehabilitation: about 26 days under 15° versus 75 days at 26–35°.

Bigger deficit, longer rehabilitation



Active knee extension deficit after strain; guideline text citing a primary study. Martin et al. (2022).

Key point: the history separates the two injuries: a direct blow for a bruise, an overstretch or forceful contraction for a strain.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle from pose landmarks in the side view; walking poses are approximate. Educational, not diagnostic.

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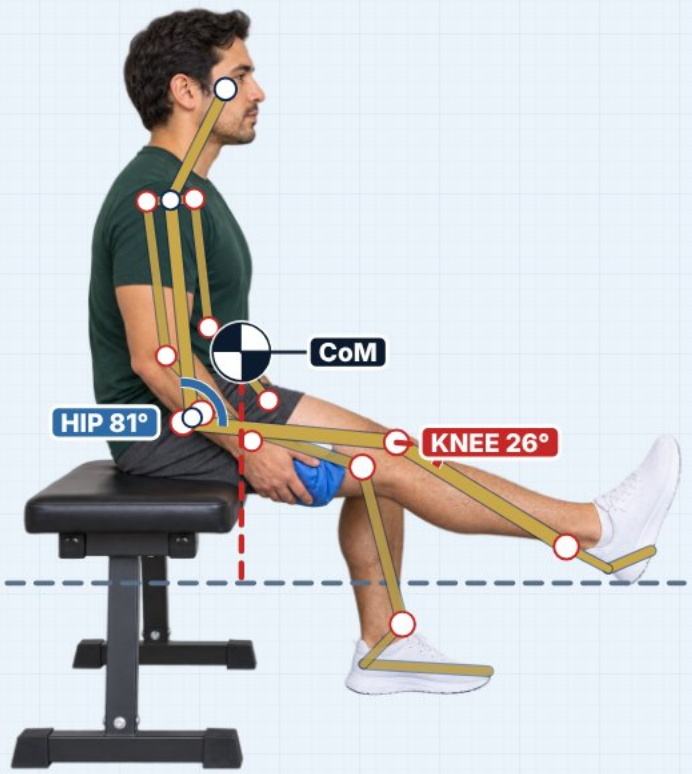
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HAMSTRING MUSCLE BRUISE VERSUS STRAIN: TELLING THEM APART

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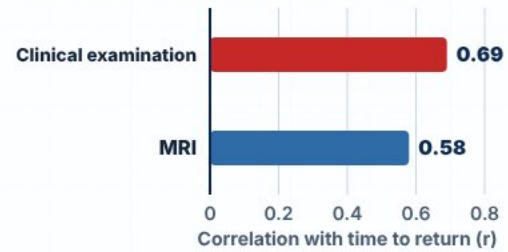
C · ICE PACK, SEATED, SIDE



Early care: settle pain and swelling

- Seated, hip flexed **81°** and knee at **26°**, holding an ice pack on the lower thigh: modalities may be used early for pain and swelling (expert opinion; ice itself is not graded).
- Imaging is typically not needed for grade I–II strains; MRI is recommended when a grade III tear is suspected, and MRI or ultrasound can help in atypical cases.

Examination predicts as well as MRI



Both P < .001; adding MRI explained only 2.8% more variance. Martin et al. (2022).

Myth: "You need a scan to tell a bruise from a tear." The mechanism guides the call, and 13% of hamstring injuries in professional football showed nothing on MRI.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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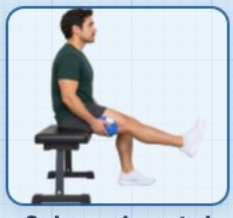
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A · Pad on thigh
Impact area

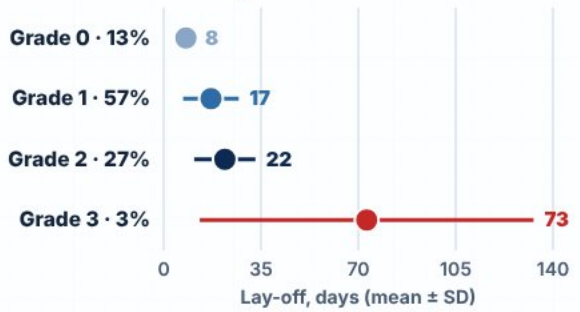


B · Slow walk
Knee 13°



C · Ice pack, seated
Hip 81°

Most strains are low grade on MRI



516 hamstring injuries in professional football, 58% scanned; % = share of injuries by MRI grade. Ekstrand et al. (2012).

Decision pathway

1. **HISTORY**
   Ask how it happened: a direct blow suggests a bruise; sudden pain while sprinting or stretching suggests a strain.
2. **EXAMINE**
   Palpate the length of the tender area and measure the knee extension deficit; both relate to recovery time.
3. **IMAGE**
   Keep MRI for a suspected grade III tear or an atypical picture; a normal scan does not exclude injury.

NOT RECOMMENDED

Ordering a scan before taking the history; treating a bruise and a strain as the same injury.

SEEK ASSESSMENT IF

Severe swelling and pain out of proportion after a blow, a palpable mass, being unable to walk, or a swollen, tender calf or thigh.

REFERENCES (APA 7)

Brooks, J. H. M., Fuller, C. W., Kemp, S. P. T., & Reddin, D. B. (2005). Epidemiology of injuries in English professional rugby union: Part 1 match injuries. *British Journal of Sports Medicine, 39*(10), 757.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Ekstrand, J., Healy, J. C., Waldén, M., Lee, J. C., English, B., & Hägglund, M. (2012). Hamstring muscle injuries in professional football: The correlation of MRI findings with return to play. *British Journal of Sports Medicine, 46*(2), 112–117.

Martin, R. L., Cibulka, M. T., Bolgla, L. A., Koc, T. A., Jr., Loudon, J. K., Manske, R. C., Weiss, L., Christoforetti, J. J., & Heiderscheit, B. C. (2022). Hamstring strain injury in athletes: Clinical practice guidelines. *Journal of Orthopaedic & Sports Physical Therapy, 52*(3), CPG1–CPG44. https://doi.org/10.2519/jospt.2022.0301

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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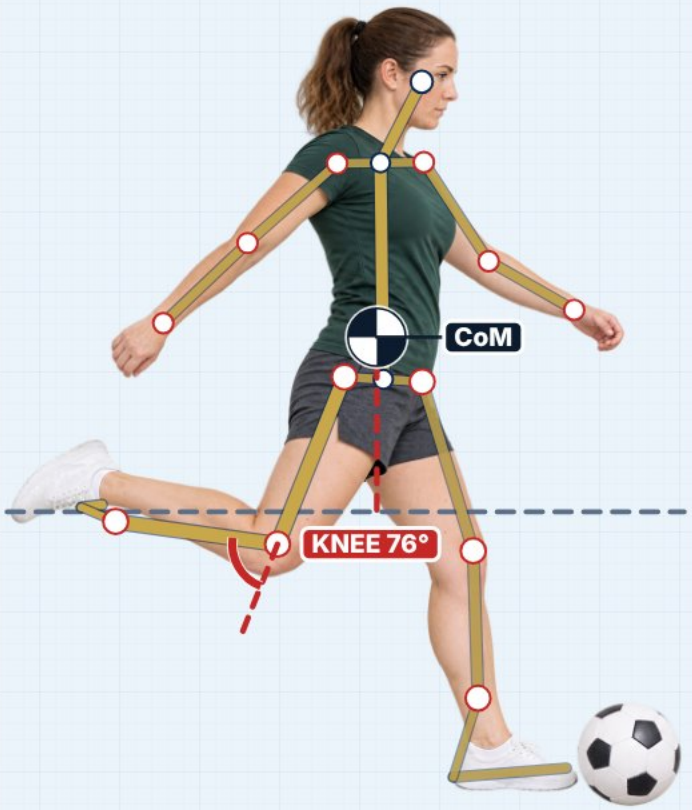
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QUADRICEPS STRAIN: THE KICKING AND SPRINTING INJURY

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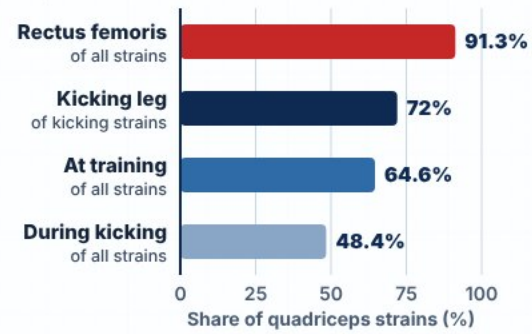
A · KICK BACKSWING, SIDE



The backswing loads the front of the thigh long

- Kicking backswing: the swing leg is drawn behind her with the knee bent ≈**76°** and the hip extended, a position that lengthens the two-joint rectus femoris just before it contracts hard.
- In elite Australian football almost every quadriceps strain involved the rectus femoris, and about half happened while kicking, mostly in the dominant kicking leg.

Kicking and the rectus femoris dominate



164 quadriceps strains in 122 players, AFL Soft Tissue Injury Registry 2014–2020. Pietsch et al. (2023).

Myth: "Quadriceps strains are just a sprinting injury." 48.4% occurred while kicking, and 63.0% of re-injuries came from kicking.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle from pose landmarks in the side view; kicking poses are approximate. Educational, not diagnostic.

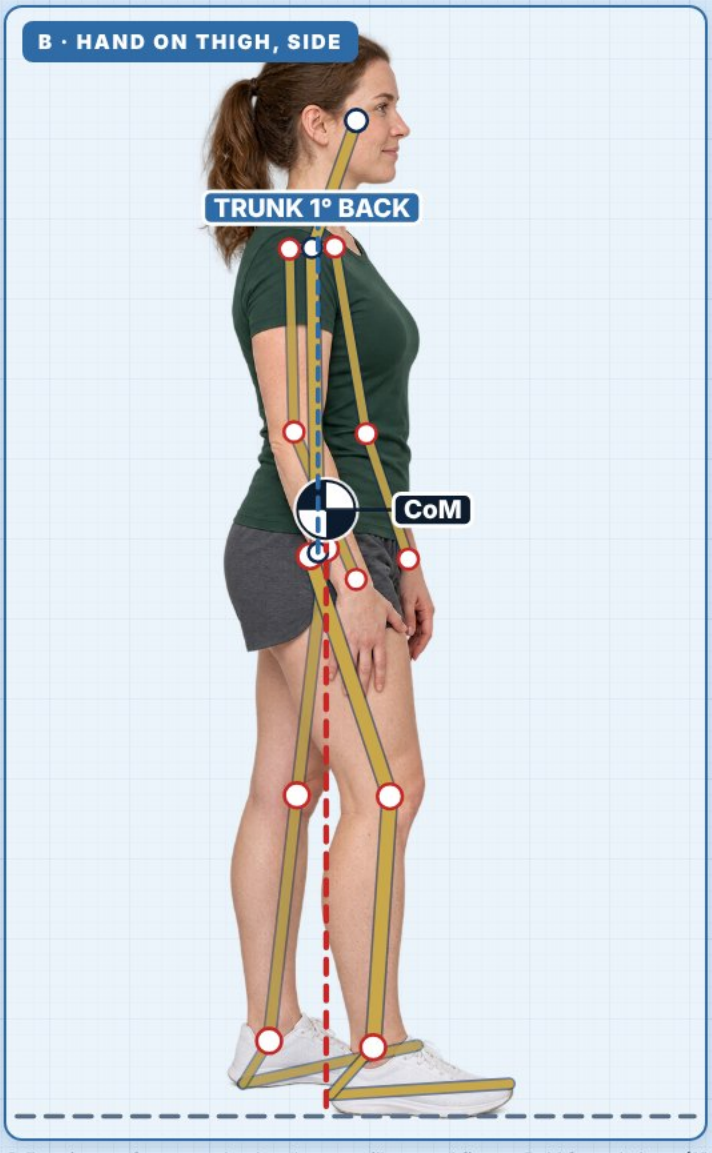
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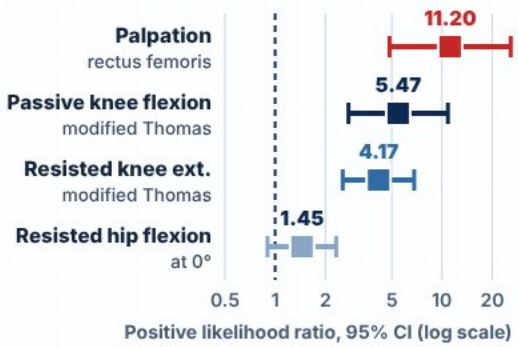


2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line from hip to shoulder points in the side view. Educational, not diagnostic.

Where it hurts guides the examination

- Standing upright (trunk within **1°** of vertical) with a hand over the front of the thigh: the typical complaint is sudden, localised pain after a kick or sprint, without a blow.
- Tenderness on palpating the rectus femoris was the most informative bedside finding; a negative palpation lowered the probability of an MRI-confirmed injury from 13% to 0%.

Palpation shifts the odds most



81 athletes with acute groin injury, MRI reference; evidence graded low to moderate. Ishøi et al. (2020).

Key point: a strain follows a non-contact stretch or kick; a "dead leg" follows a direct blow. The history separates them.

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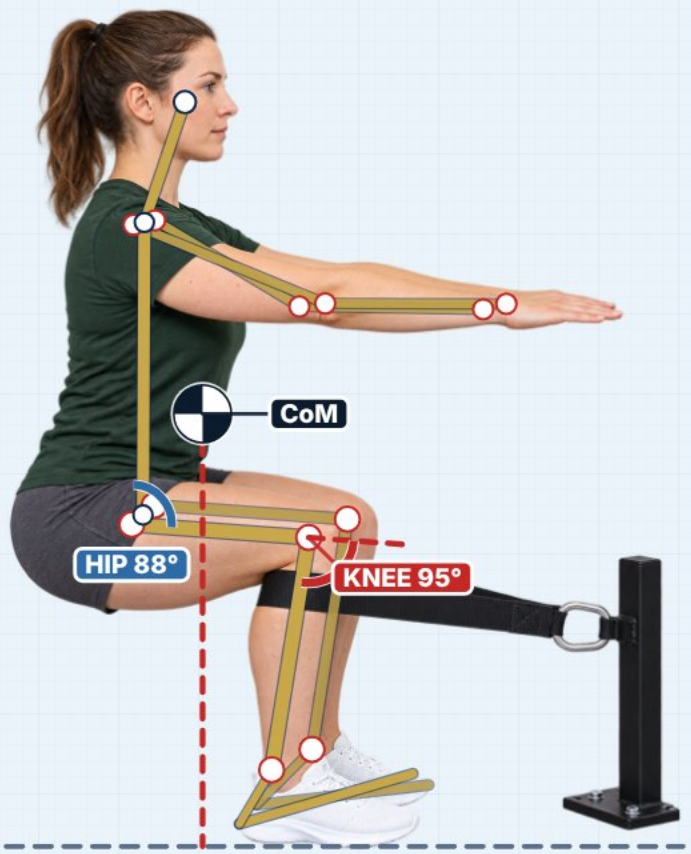
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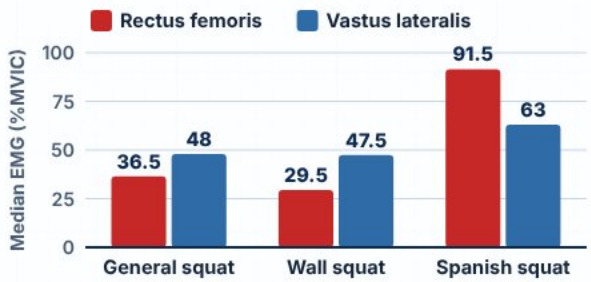
C · SPANISH SQUAT, SIDE



Spanish squat: quadriceps load without a bar

- Strap behind the knees, trunk upright, hip flexed **88°** and knee **95°**: the strap holds the shins back, so body weight is resisted mainly by the knee extensors.
- In a 3-second bottom hold, rectus femoris activity was far higher than in a general or wall squat, making it a controllable later-stage loading option once pain allows.

Rectus femoris works hardest here



22 healthy active men, 3 s isometric hold; rectus femoris greater in the Spanish squat ($p < 0.001$). Lee et al. (2022).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

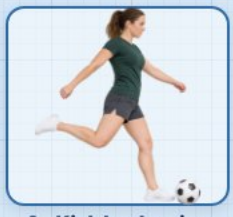
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A · Kick backswing
Knee ≈76°

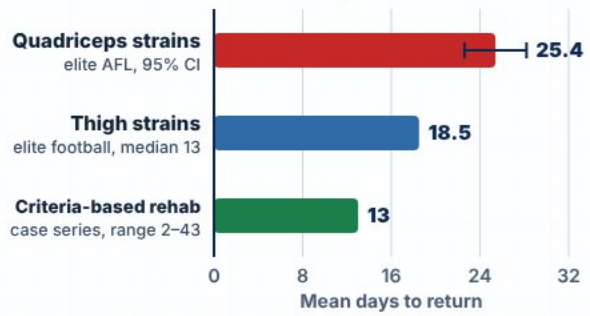


B · Front-thigh pain
Palpate first



C · Spanish squat
Quadriceps load

Return is measured in weeks, and varies



Rectus femoris strains took about 14 days longer than vasti strains (Pietsch et al., 2023). Ueblacker et al. (2015); Ishøi et al. (2020).

Decision pathway

1. **CONFIRM**
   Separate a strain from a blow; palpate the rectus femoris and test resisted knee extension.
2. **LOAD**
   Progress criteria-based loading, from isometric holds to the Spanish squat and lengthened work.
3. **RETURN**
   Rebuild sprinting and then kicking gradually; re-injury clustered within six months.

NOT RECOMMENDED

Returning straight to full-power kicking because walking and jogging feel normal.

SEEK ASSESSMENT IF

A pop high at the front of the hip, a palpable gap, a rapidly swelling or very tense thigh, or thigh pain without a clear injury.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Ishøi, L., Krommes, K., Husted, R. S., Juhl, C. B., & Thorborg, K. (2020). Diagnosis, prevention and treatment of common lower extremity muscle injuries in sport – grading the evidence: A statement paper commissioned by the Danish Society of Sports Physical Therapy (DSSF). *British Journal of Sports Medicine, 54*(9), 528–537. https://doi.org/10.1136/bjsports-2019-101228

Lee, J.-H., Kim, S., Heo, J., Park, D.-H., & Chang, E. (2022). Differences in the muscle activities of the quadriceps femoris and hamstrings while performing various squat exercises. *BMC Sports Science, Medicine and Rehabilitation, 14*, 12. https://doi.org/10.1186/s13102-022-00404-6

Pietsch, S., Green, B., Schache, A., & Pizzari, T. (2023). Epidemiology of quadriceps muscle strain injuries in elite male Australian football players. Scandinavian Journal of Medicine & Science in Sports. https://doi.org/10.1111/sms.14542

Ueblacker, P., Müller-Wohlfahrt, H.-W., & Ekstrand, J. (2015). Epidemiological and clinical outcome comparison of indirect (strain) versus direct (contusion) anterior and posterior thigh muscle injuries in male elite football players: UEFA Elite League study of 2287 thigh injuries (2001–2013). *British Journal of Sports Medicine, 49*(22), 1461–1465. https://doi.org/10.1136/bjsports-2014-094285

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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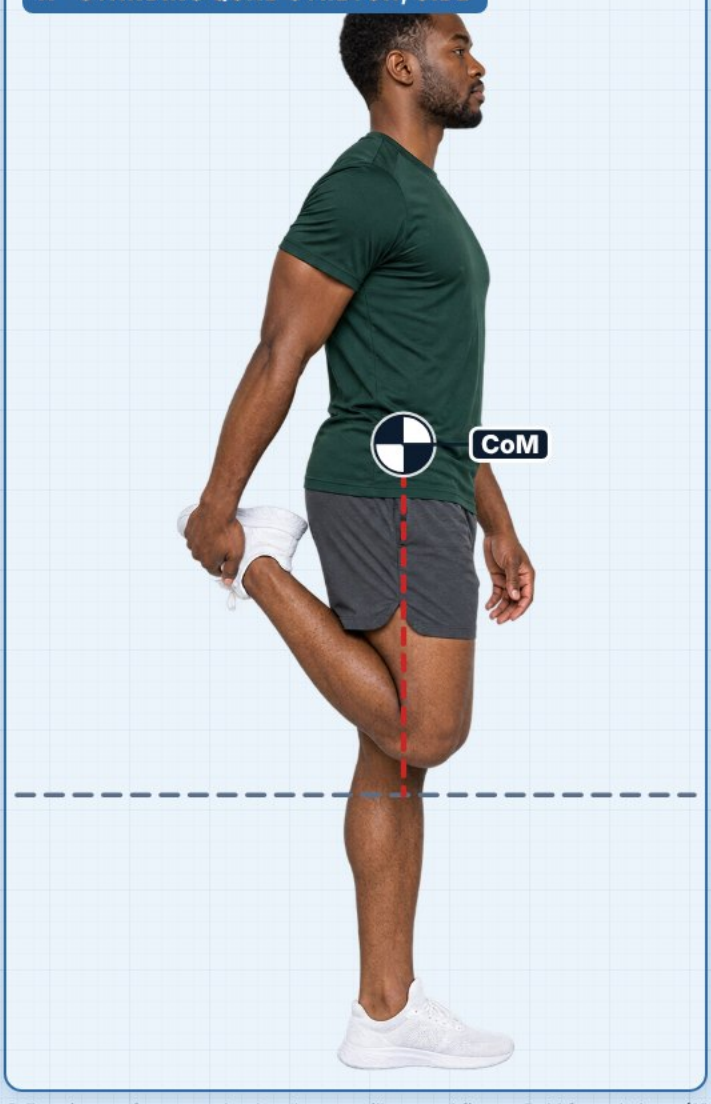
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RECTUS FEMORIS INJURY: WHY THE TWO-JOINT QUADRICEPS IS VULNERABLE

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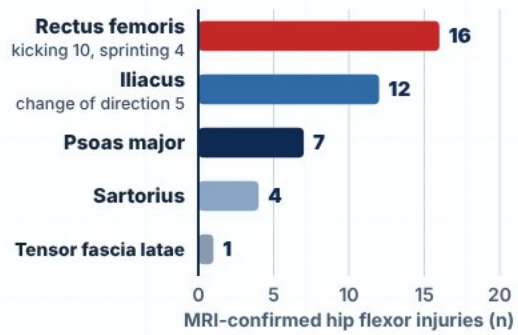
A · STANDING QUAD STRETCH, SIDE



Two joints, one long muscle

- Standing quad stretch: one heel is held towards the buttock with the thighs side by side, flexing the knee while the hip stays near neutral, so the rectus femoris is lengthened across both joints.
- It is the only quadriceps muscle that crosses the hip and the knee, and it was the hip flexor injured most often, mainly when kicking or sprinting.

Rectus femoris leads the hip flexors



33 male athletes with acute hip flexor injury, MRI within 7 days; 40 injuries; 10 of 16 rectus femoris injuries involved tendon. Serner et al. (2018).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). CoM only: the overlapping legs in this pose do not give reliable joint landmarks. Educational, not diagnostic.

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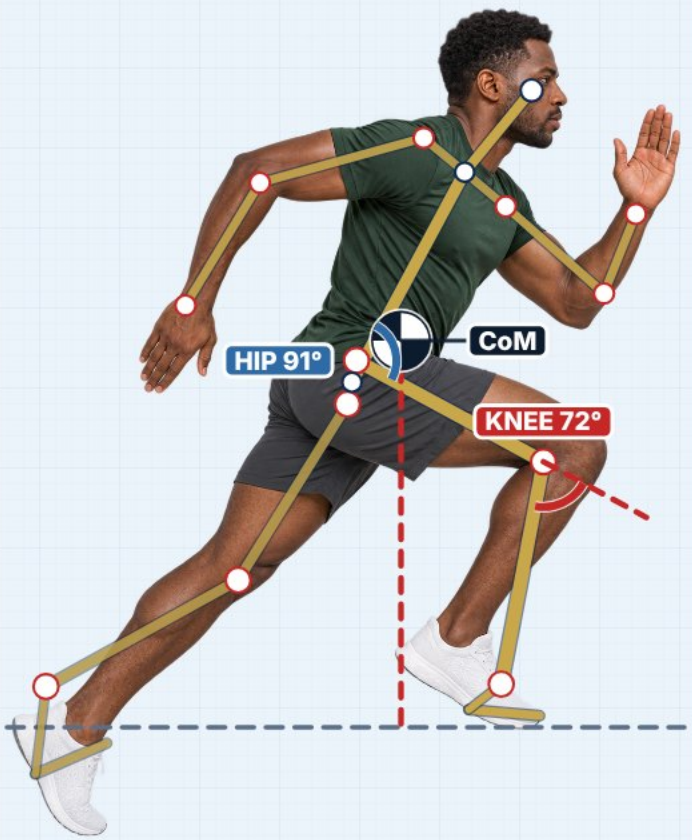
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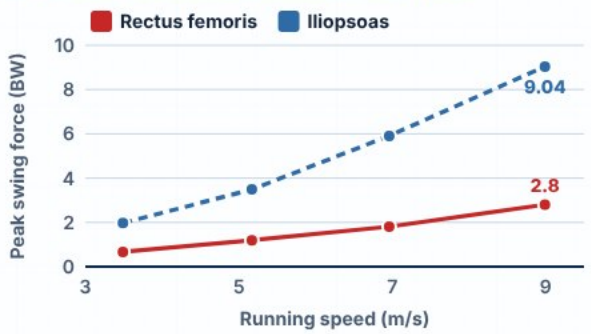
B · SPRINT PUSH-OFF, SIDE



Push-off stretches it, then it fires

- Push-off leg extended behind at the hip while the lead thigh drives forward (hip ≈**91°**, knee ≈**72°**): the trailing rectus femoris is long just as the hip flexors start to swing it through.
- Modelled rectus femoris force in swing rose about fourfold from jogging to sprinting, from 0.67 to 2.80 times body weight (iliopsoas 1.97 to 9.04).

Hip flexor demand climbs with speed



9 experienced runners; musculoskeletal model estimates (mean values; body weights). Dorn et al. (2012).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles on the lead (driving) leg from pose landmarks; sprint poses are approximate. Educational, not diagnostic.

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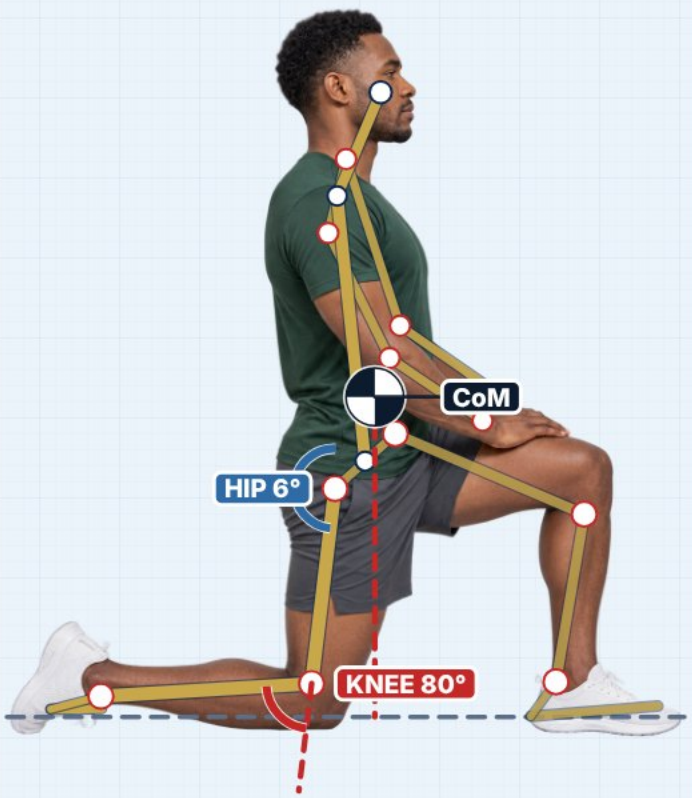
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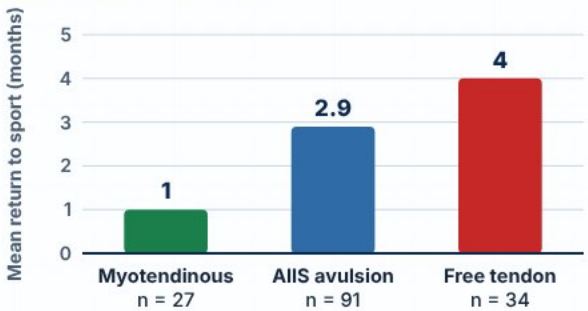
C · HALF-KNEELING, SIDE



Half-kneeling: hip extended, knee bent

- Rear knee down with the trunk upright: the rear hip sits near neutral (**6°**) and the knee is bent **≈80°**, the combination that lengthens the rectus femoris; a late-stage rehabilitation position.
- The injury site mattered: with successful conservative care, free-tendon injuries took about four times longer to return than myotendinous ones.

Site predicts time out



Systematic review, 38 studies, 152 participants; successful conservative care. AIIS = anterior inferior iliac spine. Bogwasi et al. (2023).

Myth: "A rectus femoris tear always needs an operation." 115 of 152 were treated conservatively, and 73% of operations followed failed conservative care.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles on the kneeling leg from pose landmarks in the side view. Educational, not diagnostic.

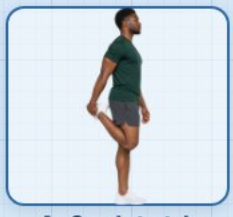
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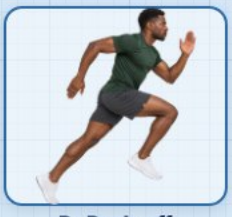
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A · Quad stretch
Knee-end length



B · Push-off
Hip-end length



C · Half-kneeling
Knee ≈80°

Full-thickness tears: surgery took twice as long



Return rate 93.3% non-operative vs 100% operative; complications 7.7% vs 18%; not randomised. Knapik et al. (2023).

Decision pathway

1. **LOCATE**
   Establish the site: muscle, myotendinous junction, free tendon or bony avulsion.
2. **SHORT FIRST**
   Load with the hip flexed and knee straight before combining hip extension with knee bend.
3. **LONG LAST**
   Add half-kneeling and push-off positions, then sprinting, and kicking last.

NOT RECOMMENDED

Forcing deep quad stretches or full-power kicking while the front of the hip is still painful.

SEEK ASSESSMENT IF

A pop at the front of the hip, a teenager with sudden hip pain after kicking or sprinting, or pain that is not easing with care.

REFERENCES (APA 7)

Bogwasi, L., Holtzhausen, L., Janse van Rensburg, D. C., Jansen van Rensburg, A., & Botha, T. (2023). Management of proximal rectus femoris injuries – do we know what we're doing? A systematic review. *Biology of Sport, 40*(2), 497–512. https://doi.org/10.5114/biolsport.2023.116454

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Dorn, T. W., Schache, A. G., & Pandy, M. G. (2012). Muscular strategy shift in human running: Dependence of running speed on hip and ankle muscle performance. *The Journal of Experimental Biology, 215*(11), 1944–1956. https://doi.org/10.1242/jeb.064527

Knapik, D. M., Alter, T. D., Ganapathy, A., Smith, M. V., Brophy, R. H., & Matava, M. J. (2023). Isolated, full-thickness proximal rectus femoris injury in competitive athletes: A systematic review of injury characteristics and return to play. Orthopaedic Journal of Sports Medicine, 11(1). https://doi.org/10.1177/23259671221144984

Serner, A., Weir, A., Tol, J. L., Thorborg, K., Roemer, F., Guermazi, A., Yamashiro, E., & Hölmich, P. (2018). Characteristics of acute groin injuries in the hip flexor muscles: A detailed MRI study in athletes. *Scandinavian Journal of Medicine & Science in Sports, 28*(2), 677–685. https://doi.org/10.1111/sms.12939

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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THIGH BRUISE (DEAD LEG): RECOVERY AND WHEN IT CAN CALCIFY

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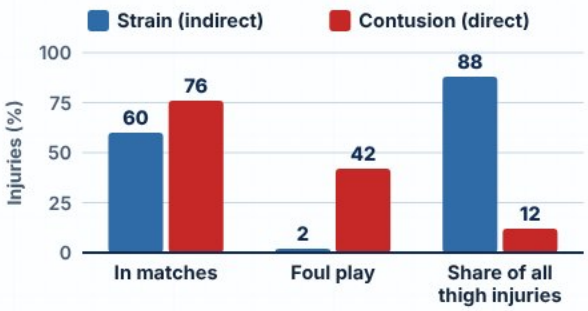
A · KNEE BENT REST, SIDE



A blow, not a stretch

- Lying on his back with one knee bent and the foot flat: resting the bruised thigh with the knee flexed keeps the quadriceps lengthened while the bleeding settles.
- A dead leg follows a direct blow from a knee, ball or stick; in elite football 42% of these contusions involved foul play, against 2% of strains.

Contusions: contact and match play



UEFA Elite Club Injury Study, 1981 players, 2001–2013; 2003 classifiable thigh muscle injuries. Ueblacker et al. (2015).

Myth: "Rest a dead leg straight and keep it still." The West Point programme rested the leg in flexion and added early flexion exercises (Ryan et al., 1991).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmarks drawn: pose detection is unreliable for lying figures. Educational, not diagnostic.

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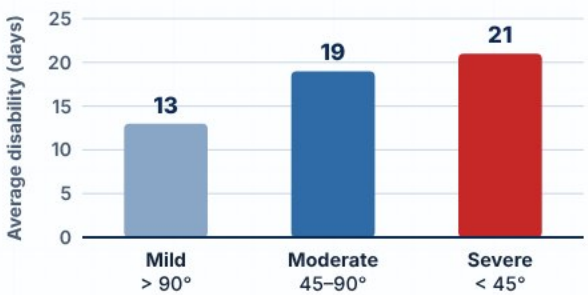
B · HEEL SLIDE, SIDE



Knee bend the next day grades severity

- Heel slide on his back, drawing one heel towards the buttock with the other leg straight: a simple test of how far the bruised thigh lets the knee bend, and a treatment.
- In West Point cadets, knee flexion range 12–24 hours after the blow sorted contusions into mild, moderate and severe, and the time lost rose with severity.

Less knee bend, more days lost



117 quadriceps contusions in cadets; knee flexion 12–24 h after injury; three-phase programme. Ryan et al. (1991).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmarks drawn: pose detection is unreliable for lying figures. Educational, not diagnostic.

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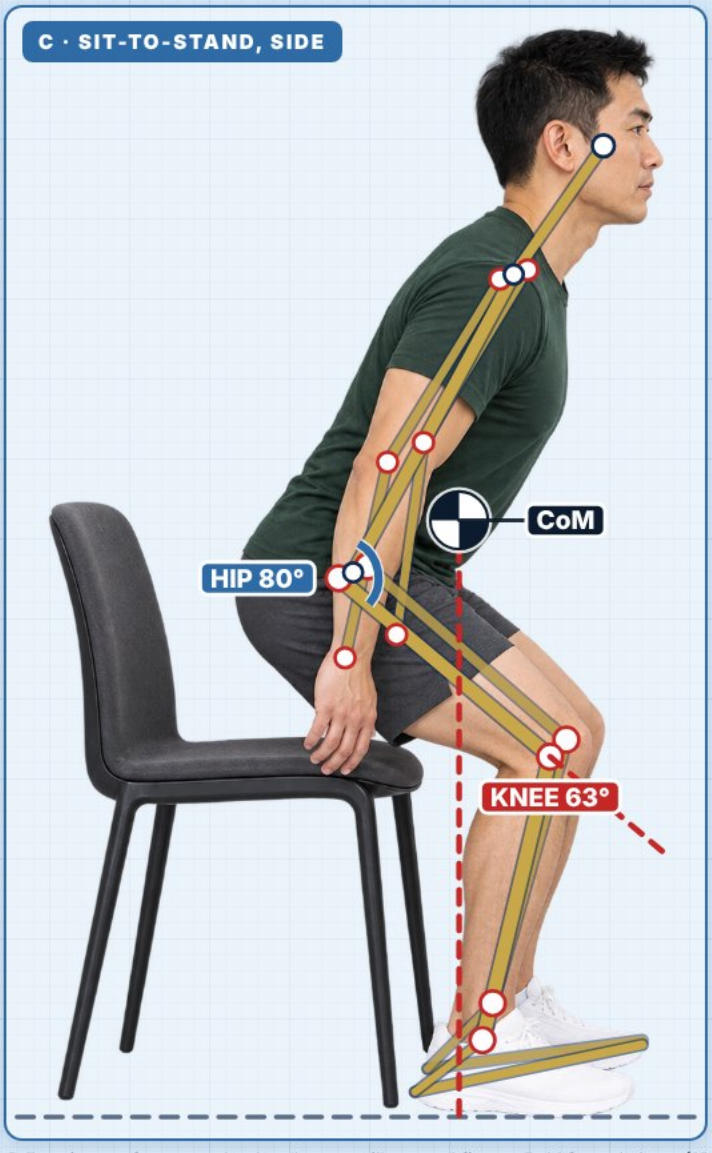
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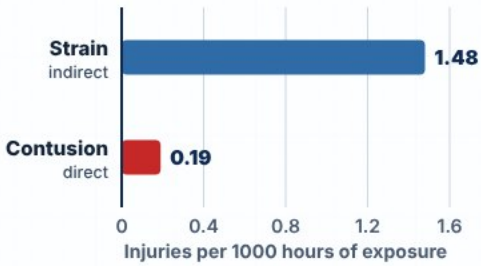
C · SIT-TO-STAND, SIDE



Rising from a chair needs knee bend

- Halfway up from a chair with the trunk leaning forward (hip ≈**80°**, knee ≈**63°**): standing up asks the quadriceps to work through a bend that a bruised thigh may not allow yet.
- In elite football contusions were far less frequent than strains, and most settled quickly; regaining pain-free knee bend is the first milestone.

Contusions are the smaller share



Thigh muscle injury incidence, UEFA Elite Club Injury Study; anterior and posterior thigh combined. Ueblacker et al. (2015).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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A · Rest bent
Quadriceps long

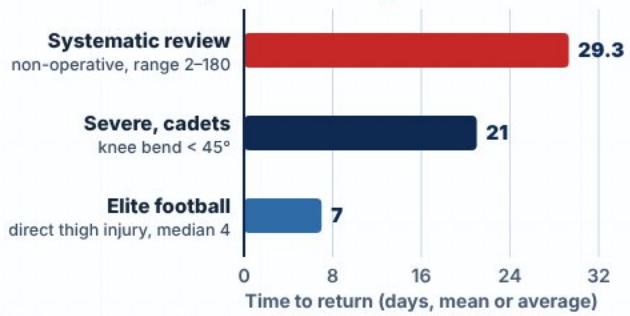


B · Heel slide
Severity gauge



C · Sit-to-stand
Knee ≈63°

Most settle fast; the tail is long



Review: 7 studies, all level IV evidence. Haws et al. (2017); Ryan et al. (1991); Ueblacker et al. (2015).

Decision pathway

1. **PROTECT**
   Limit bleeding early and rest the knee in a bent position.
2. **RESTORE**
   Regain pain-free knee bend with heel slides; track the range day by day.
3. **RELOAD**
   Strengthen and return to running and contact as knee bend and strength return.

NOT RECOMMENDED

Forceful massage or stretching through pain in the first days after a heavy blow.

SEEK ASSESSMENT IF

Severe or escalating pain, a very tense thigh, a firm lump, or knee bend that will not return after two to three weeks.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Haws, B. E., Luo, T. D., Al'Khafaji, I. M., Rogers, J. P., Botros, D. B., & Freehill, M. T. (2017). Definitive management of thigh contusions in athletes: But how definitive? A systematic review. *Journal of ISAKOS, 2*(2), 67. https://doi.org/10.1136/jisakos-2016-000107

Ryan, J. B., Wheeler, J. H., Hopkinson, W. J., Arciero, R. A., & Kolakowski, K. R. (1991). Quadriceps contusions: West Point update. *The American Journal of Sports Medicine, 19*(3), 299–304.

Ueblacker, P., Müller-Wohlfahrt, H.-W., & Ekstrand, J. (2015). Epidemiological and clinical outcome comparison of indirect (strain) versus direct (contusion) anterior and posterior thigh muscle injuries in male elite football players: UEFA Elite League study of 2287 thigh injuries (2001–2013). *British Journal of Sports Medicine, 49*(22), 1461–1465. https://doi.org/10.1136/bjsports-2014-094285

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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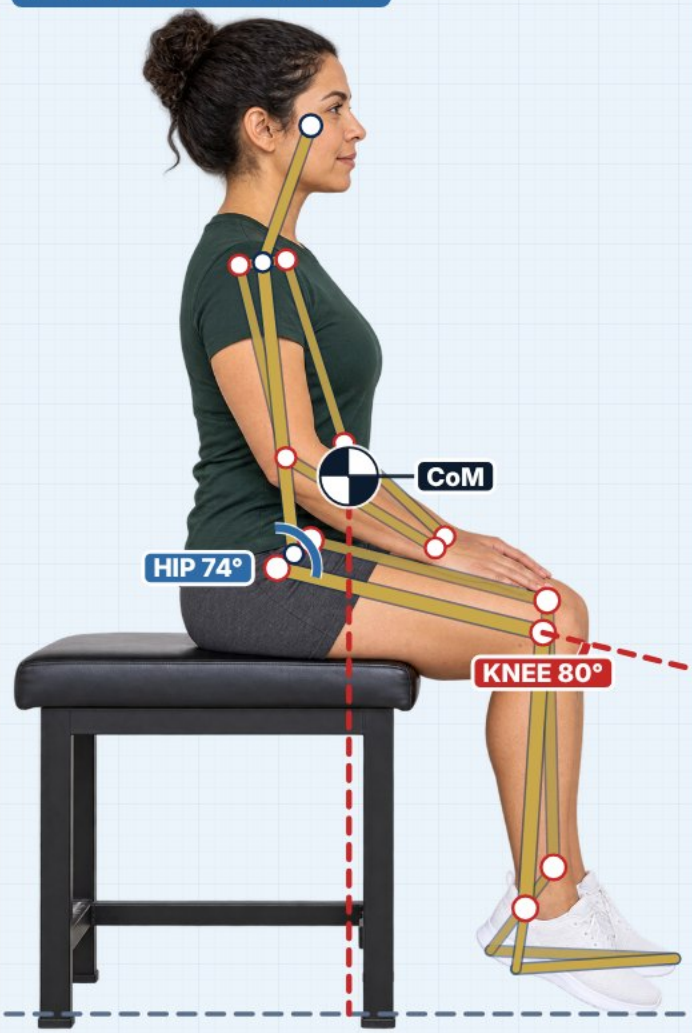
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MYOSITIS OSSIFICANS: WHEN A THIGH BRUISE TURNS TO BONE

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A · SEATED KNEE BEND, SIDE



Knee bend is the first target

- Seated on a high bench with the lower legs hanging, knee bent ≈**80°**: gravity-assisted knee bending is an early, gentle way to win back range after a heavy thigh bruise.
- Walking needs less than 90° of knee bend, but stairs and chairs need 90–120°; knee motion below 120° was also linked to myositis ossificans in cadets.

How much bend daily life needs



20 healthy older adults, flexible electrogoniometry; walking shown up to 90°. Rowe et al. (2000).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

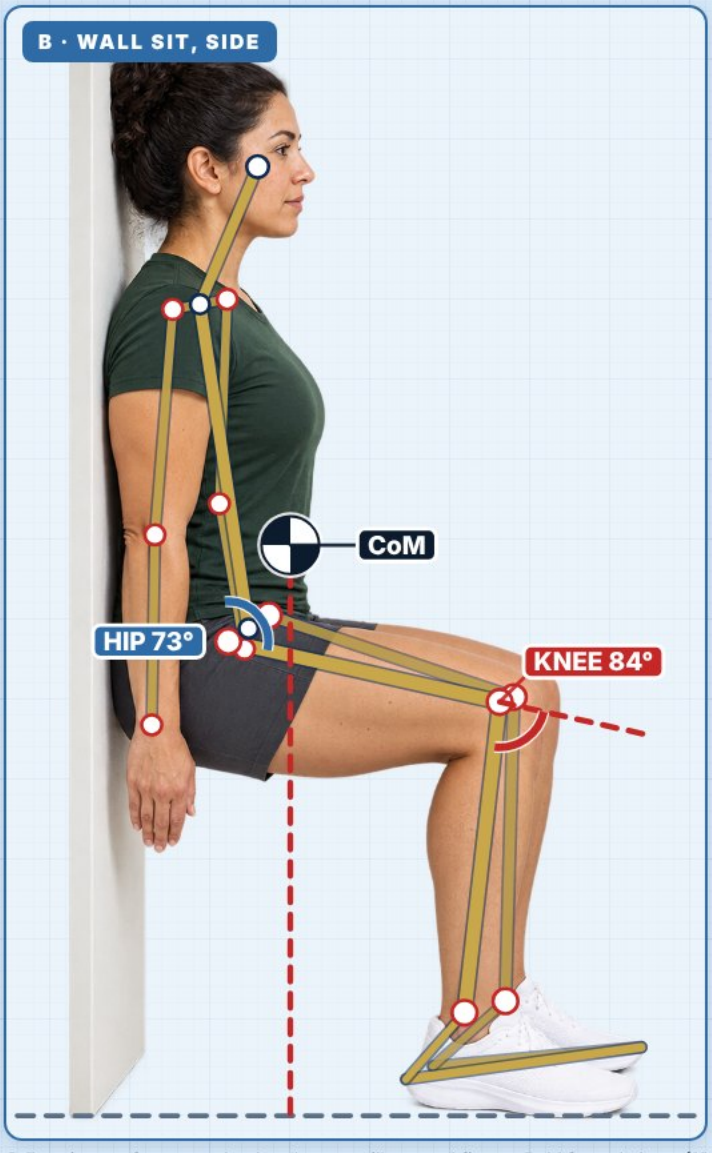
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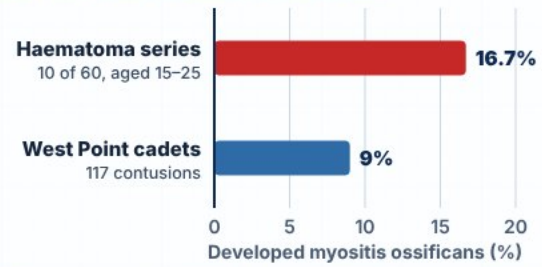
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A bruise that turns to bone

- Wall sit with the back flat on the wall, knees ≈**84°** and hips ≈**73°**: a static quadriceps load near 90°, the bend needed for stairs and chairs, used once pain allows.
- Myositis ossificans is benign bone forming inside a bruised muscle; it may show on X-ray from 2–4 weeks and appears as a firm, painful mass with lost knee bend.

Roughly one in ten to one in six



16.7% calculated from 10/60. Rothwell (1982); Ryan et al. (1991). A review reports 9–20% in US military academies (Lamplot & Matava, 2016).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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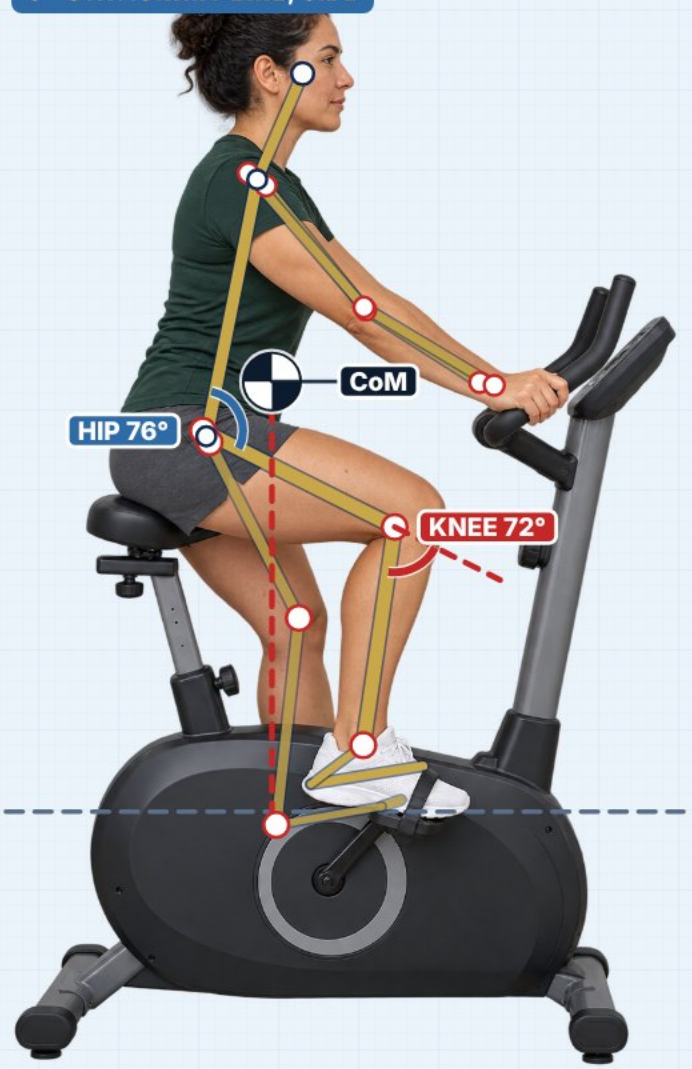
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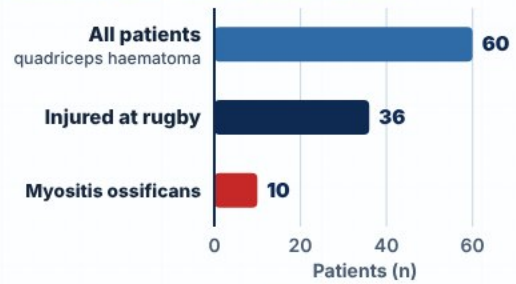
C · STATIONARY BIKE, SIDE



Cycling restores range under control

- Stationary bike, upper pedal leg with the knee ≈**72°** and the hip ≈**76°**: each revolution takes the knee through a repeatable, low-impact arc, so range and loading can be progressed together.
- Contact sport supplies the blows: in one prospective series most quadriceps haematomas came from rugby, and about one in six went on to ossify.

Contact sport, then calcification



Prospective clinical study of 60 patients with quadriceps haematoma. Rothwell (1982).

Myth: "Once it has calcified, the thigh will never be normal again." Most patients regain full knee and hip motion and return to sport (Lamplot & Matava, 2016).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view; pedalling positions are approximate. Educational, not diagnostic.

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A · Seated knee bend
Knee ≈80°

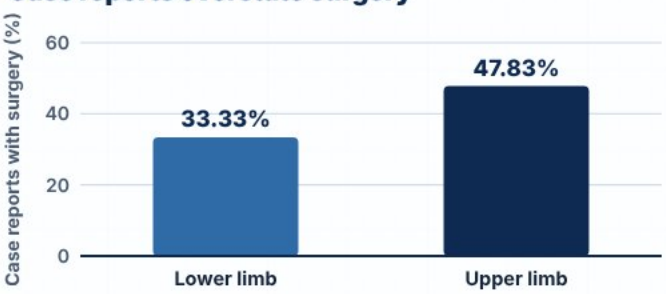


B · Wall sit
Knee ≈84°



C · Stationary bike
Low-impact arc

Case reports overstate surgery



89 patients in 77 case reports, 1972–2020; case reports favour severe cases. Stammer et al. (2024).

Decision pathway

1. **ACT EARLY**
   Treat a heavy bruise promptly; delay over 3 days, effusion and prior injury were risk factors.
2. **REGAIN BEND**
   Restore knee flexion gradually: seated bends, wall sits, then cycling, guided by pain.
3. **IMAGE IF STUCK**
   If a firm lump persists or range stalls, imaging can confirm a benign process.

NOT RECOMMENDED

Aggressive massage or forced stretching of a firm, painful bruised thigh.

SEEK ASSESSMENT IF

A firm mass or lost knee bend after 2–3 weeks, a thigh lump without injury or one that keeps growing, or severe escalating pain.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Lamplot, J. D., & Matava, M. J. (2016). Thigh injuries in American football. *The American Journal of Orthopedics, 45*(6), E308–E318.

Rothwell, A. (1982). Quadriceps haematoma: A prospective clinical study. *Clinical Orthopaedics and Related Research, 171*, 97.

Rowe, P. J., Myles, C. M., Walker, C., & Nutton, R. (2000). Knee joint kinematics in gait and other functional activities measured using flexible electrogoniometry: How much knee motion is sufficient for normal daily life? *Gait & Posture, 12*(2), 143–155. https://doi.org/10.1016/S0966-6362(00)00060-6

Ryan, J. B., Wheeler, J. H., Hopkinson, W. J., Arciero, R. A., & Kolakowski, K. R. (1991). Quadriceps contusions: West Point update. *The American Journal of Sports Medicine, 19*(3), 299–304.

Stammer, A., Ashwood, N., Amara, V., Suryawanshi, S., Wilson, P., & Dekker, A. (2024). The anatomical basis for surgical intervention in myositis ossificans: A systematic review. Clinical Anatomy. https://doi.org/10.1002/ca.24238

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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QUADRICEPS WEAKNESS AFTER KNEE INJURY: WHY IT LINGERS

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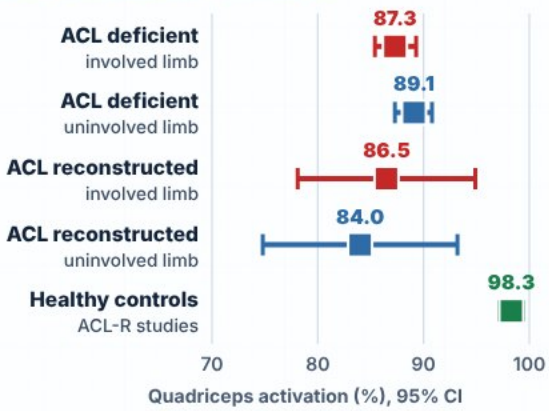
A · STRAIGHT-LEG RAISE, SIDE



The nervous system holds the brake on

- Straight-leg raise on his back, one knee bent and the other leg lifted straight: an early exercise that asks the quadriceps to lock the knee while swelling and pain are still present.
- After knee injury the quadriceps cannot be fully activated (arthrogenic muscle inhibition), and the "good" leg was often inhibited too, so side-to-side comparison can hide the deficit.

Both legs fall short of controls



Systematic review, 17 data sets from 15 studies; weighted mean activation. Hart et al. (2010).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmarks drawn: pose detection is unreliable for lying figures. Educational, not diagnostic.

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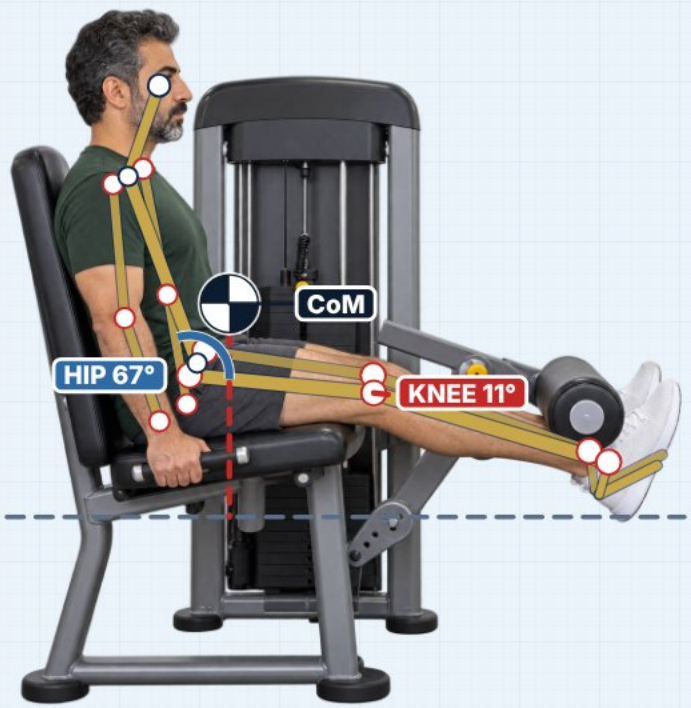
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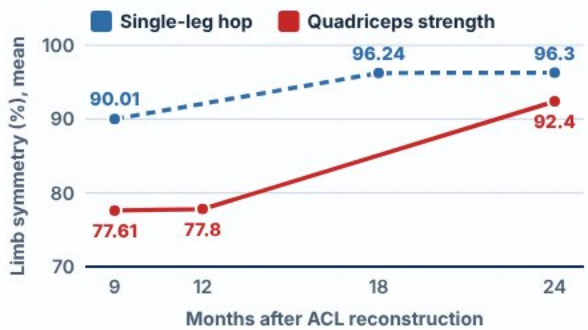
B · KNEE EXTENSION, SIDE



Isolate the quadriceps, then measure it

- Leg-extension machine at the top of the lift, knee **≈11°** from straight: open-chain extension isolates the quadriceps, so a weak side cannot hide behind the hip and ankle.
- Nine months after reconstruction, quadriceps symmetry averaged 77.6% while hop symmetry was about 90%; strength kept improving up to 24 months.

Hops recover before strength



82 people cleared to return to activity; concentric strength at 60°/s; injured ÷ uninjured × 100. Curran et al. (2020).

Myth: "If my hop tests are about 90%, my quadriceps must have recovered." At 9 months, strength symmetry averaged only 77.6%.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle from pose landmarks in the side view. Educational, not diagnostic.

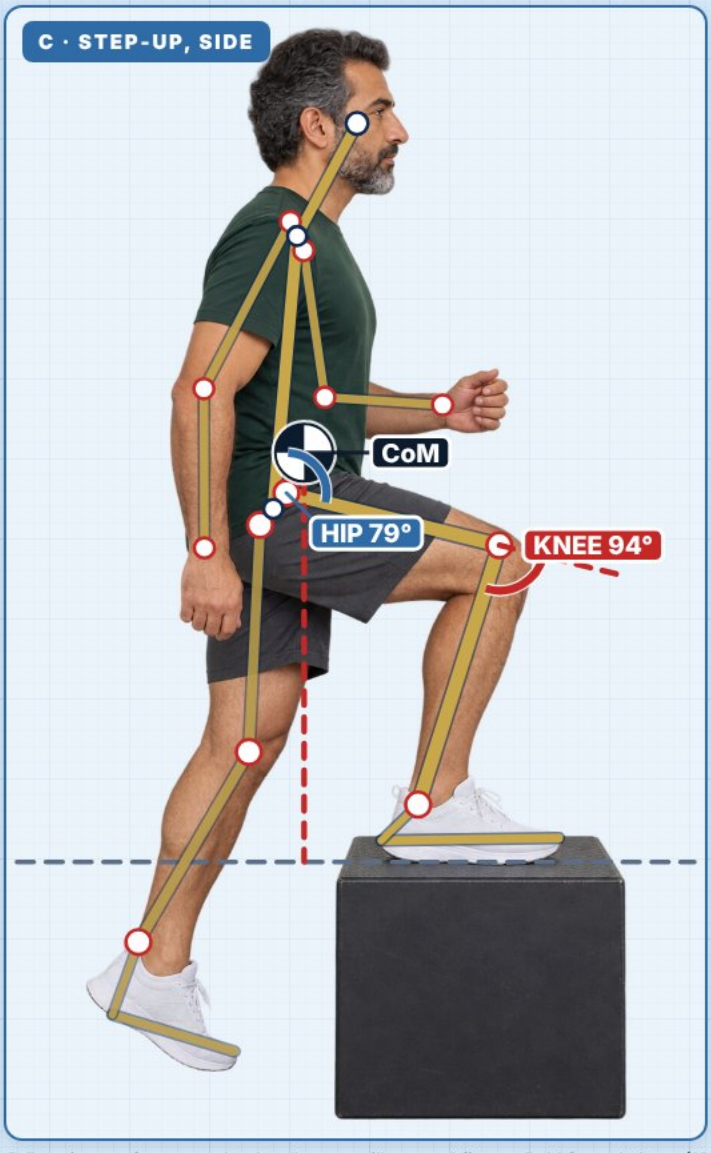
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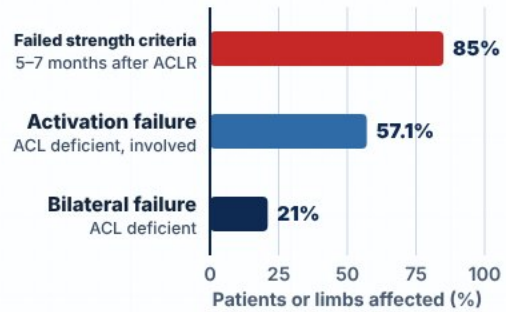
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Step-ups load one leg at a time

- Stepping up onto a box with the lead hip ≈**79°** and knee ≈**94°**: the lead quadriceps must lift body weight on its own, a closed-chain progression after isolated work.
- Deficits are common: most people 5–7 months after reconstruction had not met either the strength or the symmetry criterion.

Weakness is the rule, not the exception



Activation failure = below 95%. Walaszek et al. (2023), n = 173; Hart et al. (2010).

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A · Straight-leg raise
Early activation

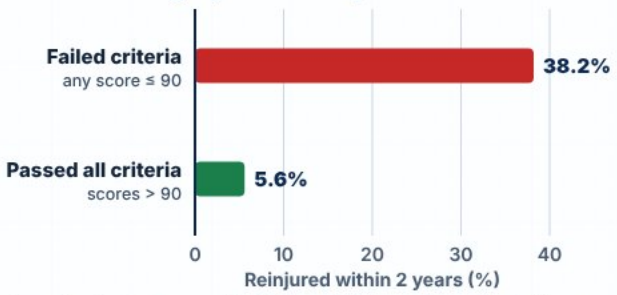


B · Knee extension
Isolated strength



C · Step-up
Knee ≈94°

Symmetric strength, fewer reinjuries



106 patients in pivoting sports; HR 0.16 (p = 0.075); each month of delay up to 9 months cut reinjury by 51%. Grindem et al. (2016).

Decision pathway

1. **ACTIVATE**
   Start with quadriceps setting and straight-leg raises while swelling settles.
2. **ISOLATE**
   Add machine knee extension so the weak side cannot hide; test both legs.
3. **CLEAR**
   Return on objective criteria, quadriceps symmetry above 90%, and keep training after.

NOT RECOMMENDED

Relying on hop tests or time since surgery alone to decide on return to pivoting sport.

SEEK ASSESSMENT IF

The knee keeps swelling after loading, locks or gives way, or there is fever, a hot red knee, or calf pain and swelling.

REFERENCES (APA 7)

Curran, M. T., Bedi, A., Kujawa, M., & Palmieri-Smith, R. (2020). A cross-sectional examination of quadriceps strength, biomechanical function, and functional performance from 9 to 24 months after anterior cruciate ligament reconstruction. The American Journal of Sports Medicine, 48(10). https://doi.org/10.1177/0363546520940310

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Grindem, H., Snyder-Mackler, L., Moksnes, H., Engebretsen, L., & Risberg, M. A. (2016). Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: The Delaware-Oslo ACL cohort study. *British Journal of Sports Medicine, 50*(13), 804.

Hart, J. M., Pietrosimone, B., Hertel, J., & Ingersoll, C. D. (2010). Quadriceps activation following knee injuries: A systematic review. *Journal of Athletic Training, 45*(1), 87–97. https://doi.org/10.4085/1062-6050-45.1.87

Walaszek, M. C., Grindstaff, T. L., Hart, J. M., Birchmeier, T., Triplett, A., Collins, K., Harkey, M., Shingles, M., Straus, M., & Kuenze, C. (2023). Quadriceps strength and knee-related symptom state 6 months after anterior cruciate ligament reconstruction. *Journal of Athletic Training, 58*(6), 536–541. https://doi.org/10.4085/1062-6050-0207.22

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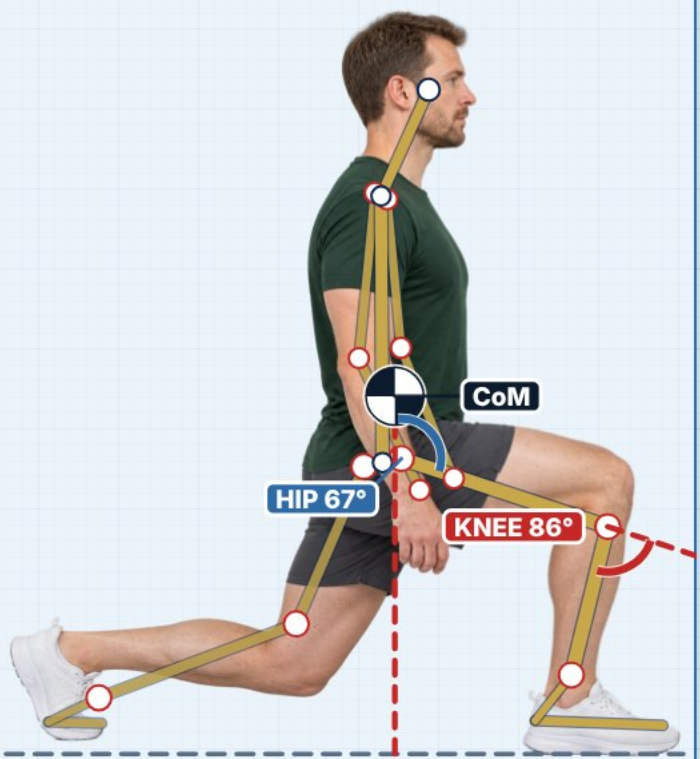
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QUADRICEPS TENDINOPATHY: PAIN ABOVE THE KNEECAP

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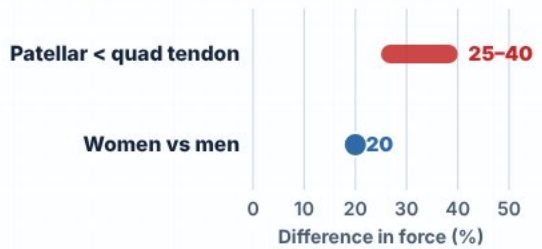
A · FORWARD LUNGE, SIDE



Deep bends load the tendon two ways

- Forward lunge with the front knee bent ≈**86°**: beyond about 60° the quadriceps tendon starts to press on the femoral groove, so it is compressed as well as pulled.
- For the same knee-extending effort the quadriceps tendon carried more force than the patellar tendon, and patellofemoral compression peaked at 90°.

The quadriceps tendon carries more



Patellar tendon force 25–40% lower than quadriceps tendon force; patellar forces about 20% higher in women. 20 loaded knees plus 20 specimens, knee model. Nisell & Ekholm (1985).

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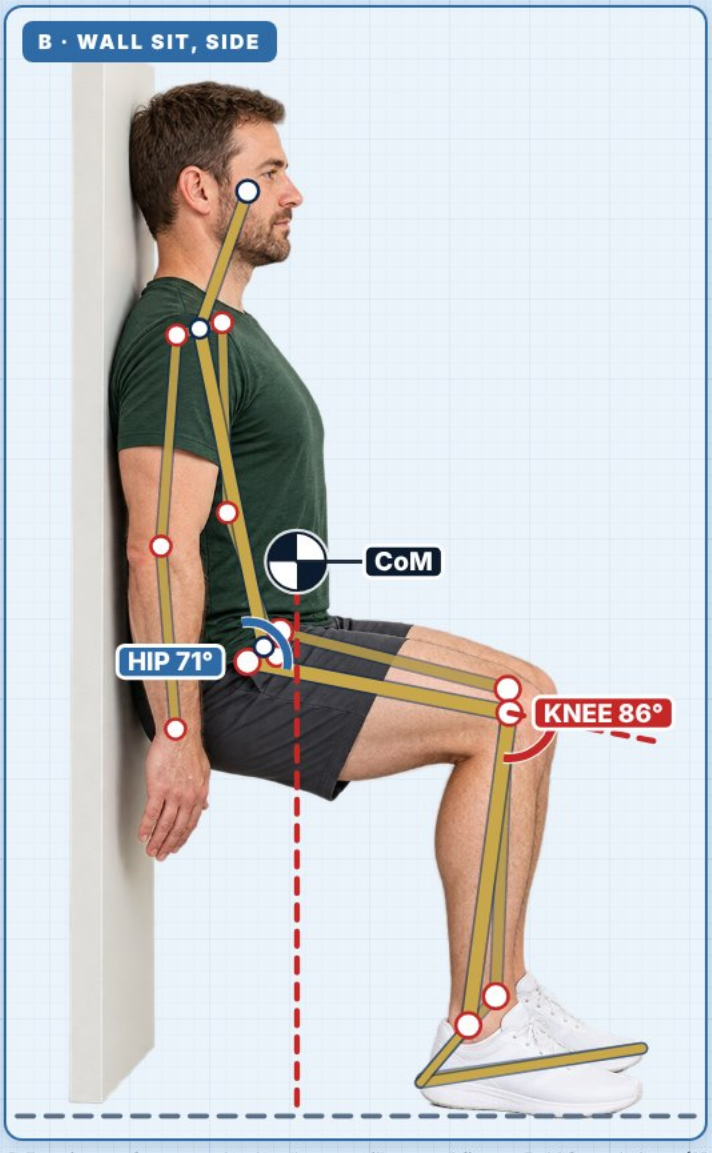
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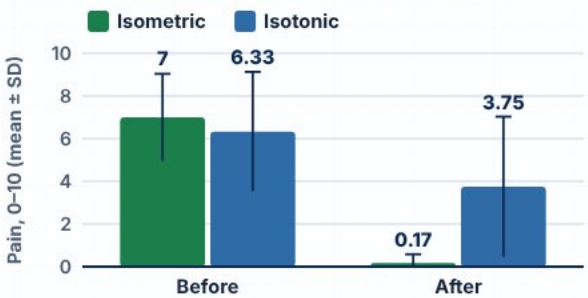
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Isometric holds can settle pain

- Wall sit with the back on the wall, knees ≈**86°** and hips ≈**71°**: a static quadriceps hold with no movement through the painful range; the depth can be set to what the tendon tolerates.
- In a small cross-over trial, heavy isometric contractions reduced tendon pain far more than isotonic work, and the effect lasted at least 45 minutes.

Pain on a decline squat, before and after



6 volleyball players with patellar tendinopathy, randomised cross-over; applied here by analogy. Rio et al. (2015).

Key point: an isometric hold is a short-term pain tool that can allow training; it is not a cure on its own.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

QUADRICEPS TENDINOPATHY: PAIN ABOVE THE KNEECAP

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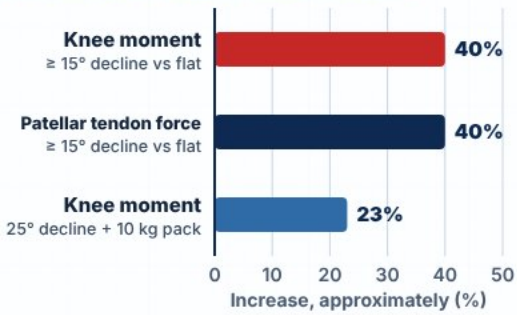
C · DECLINE SQUAT, SIDE



A decline board turns up the dose

- Single-leg squat on a decline board, stance knee bent ≈**98°**, other leg held forward: the slope lets the knee travel forward and shifts work from the hip and ankle to the knee extensors.
- Steeper boards and added weight raise knee load, so the board is a dose dial to progress gradually, not a starting point for an irritable tendon.

Slope and load raise knee demand



5 participants, decline angles 0–30°; patellar tendon data applied by analogy. Zwerver et al. (2007).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle on the stance leg from pose landmarks in the side view. Educational, not diagnostic.

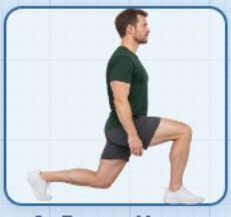
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A · Forward lunge
Knee ≈86°

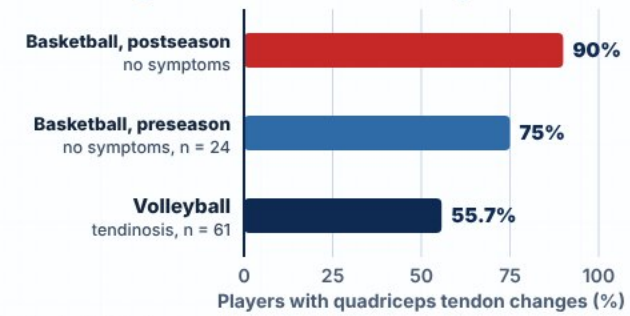


B · Wall sit
Isometric hold



C · Decline squat
Dose dial

Scan changes are common without pain



Basketball MRI changes showed no link to symptoms; review summary of earlier studies. King et al. (2019).

Decision pathway

1. **CALM**
   Reduce painful deep-flexion and decline loading; use isometric holds to settle pain.
2. **LOAD**
   Build heavy, slow quadriceps strength through a tolerable range.
3. **PROGRESS**
   Add depth, then decline work and jumping, guided by next-day symptoms.

NOT RECOMMENDED

Treating a scan finding alone as the cause of pain; complete rest from all loading.

SEEK ASSESSMENT IF

Sudden pain above the kneecap with a gap, unable to straighten the knee or lift the straight leg, or a hot swollen knee with fever.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

King, D., Yakubek, G., Chughtai, M., Khlopas, A., Saluan, P., Mont, M. A., & Genin, J. (2019). Quadriceps tendinopathy: A review—part 1: Epidemiology and diagnosis. *Annals of Translational Medicine, 7*(4), 71. https://doi.org/10.21037/atm.2019.01.58

Nisell, R., & Ekholm, J. (1985). Patellar forces during knee extension. Journal of Rehabilitation Medicine, 17(2). https://doi.org/10.2340/1650197785176374

Rio, E., Kidgell, D., Purdam, C., Gaida, J., Moseley, G. L., Pearce, A. J., & Cook, J. (2015). Isometric exercise induces analgesia and reduces inhibition in patellar tendinopathy. *British Journal of Sports Medicine, 49*(19), 1277–1283. https://doi.org/10.1136/bjsports-2014-094386

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

Zwerver, J., Bredeweg, S. W., & Hof, A. L. (2007). Biomechanical analysis of the single-leg decline squat. *British Journal of Sports Medicine, 41*(4), 264.

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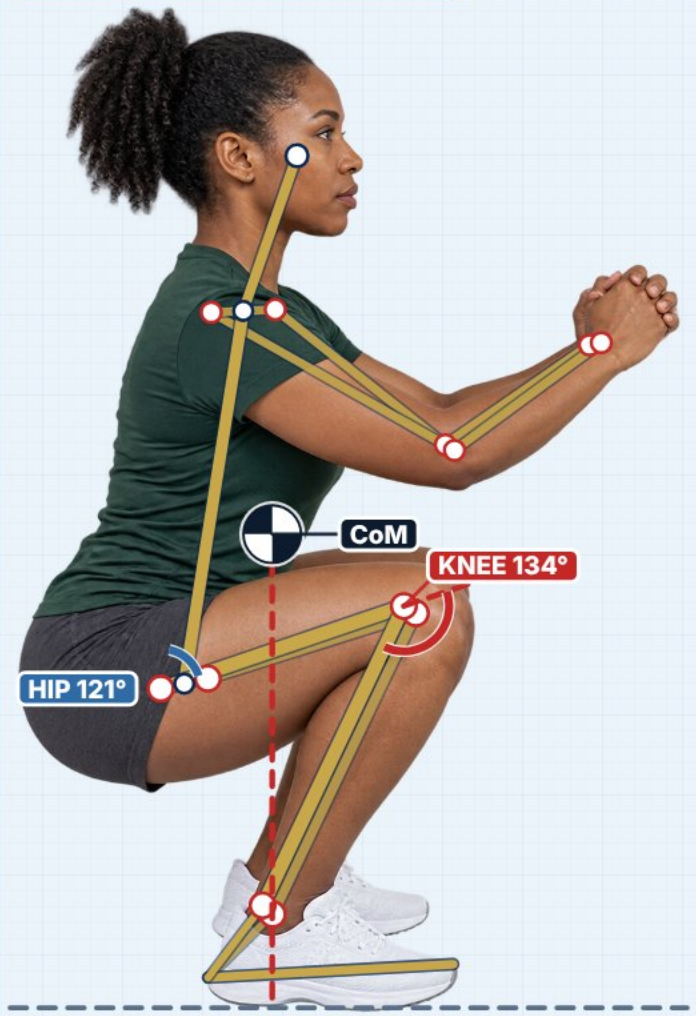
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FRONT-OF-THIGH PAIN WHEN SQUATTING: LOAD, DEPTH AND KNEE POSITION

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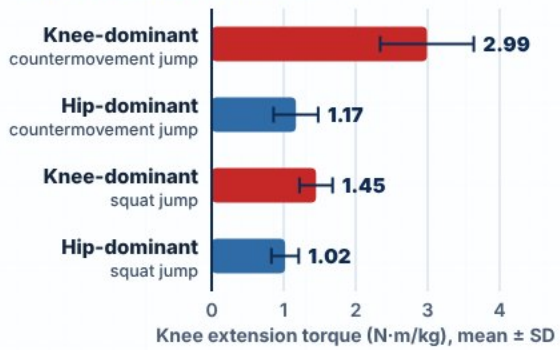
A · KNEES-FORWARD SQUAT, SIDE



Knees forward: the quadriceps take the load

- Deep squat with the knees travelling well past the toes (knee ≈**134°**, hip ≈**121°**): the knee sits far from the body's line of weight, so knee-extensor demand is high.
- In jumps started from a squat, a knee-dominant posture raised knee extension torque up to about 2.6 times that of a hip-dominant posture.

Posture is a dial for knee load



12 male sports-science students; jump tasks used as an analogue of the two squat styles. Seki et al. (2023).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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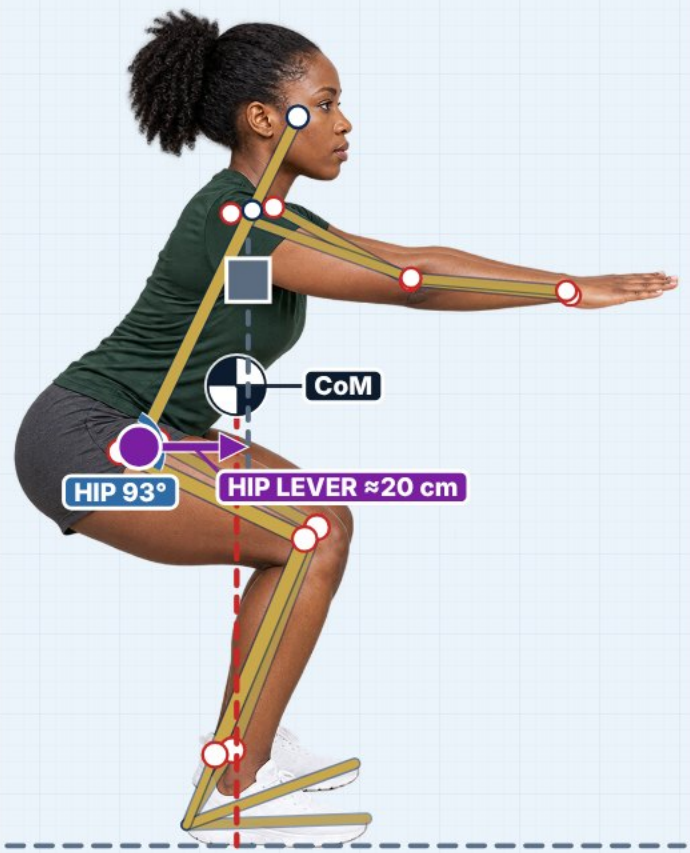
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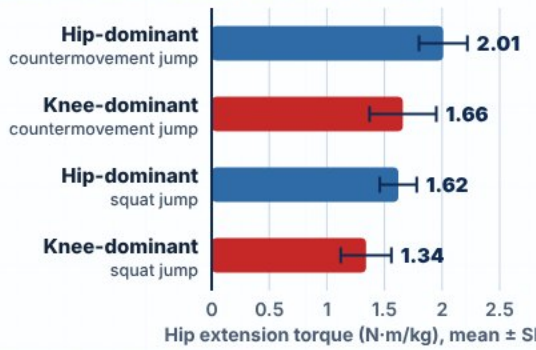
B · HIPS-BACK SQUAT, SIDE



Hips back: the work moves to the hip

- Hips pushed back with the trunk inclined and the shins more vertical: hip flexed ≈**93°** with the upper body ≈**20 cm** in front of the hip, ≈**78 N·m** held by the hip extensors.
- The hip-dominant posture raised hip extension torque while lowering knee torque, so it can unload a painful knee extensor without stopping the squat.

What the knee loses, the hip gains



Same 12 participants and tasks; posture × movement interaction for knee torque $p < 0.001$. Seki et al. (2023).

Myth: "Your knees must never go past your toes." Restricting knee travel does not remove load; it moves it to the hip.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Educational, not diagnostic.

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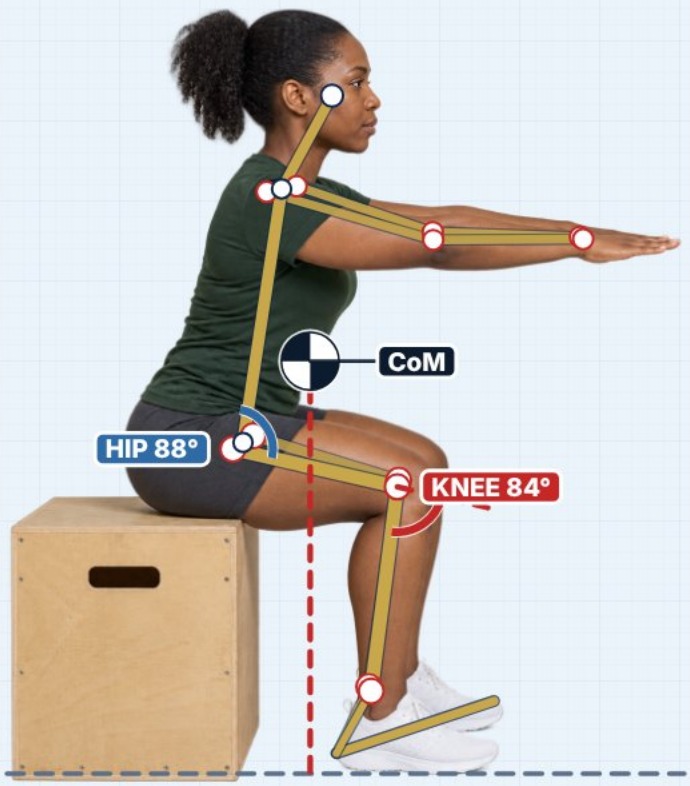
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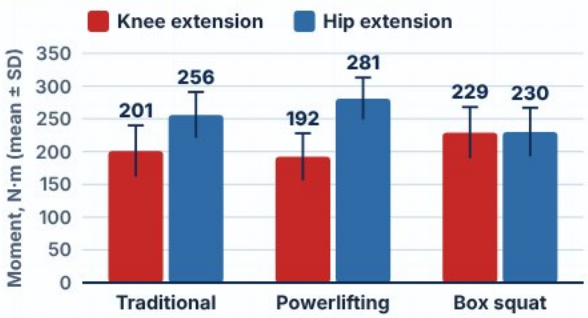
C · BOX SQUAT, SIDE



A box limits depth, not always knee load

- Sitting lightly on a box with the thighs just above parallel (hip ≈**88°**, knee ≈**84°**): a box set above the painful depth lets training continue while symptoms settle.
- In powerlifters at 70% 1RM the box squat had the highest knee extension moment of three styles, so shin angle alone does not tell you the knee load.

Box squat: knee moment stayed high



12 male powerlifters at 70% 1RM; wide stances. Swinton et al. (2012).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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A · Knees forward
Knee ≈134°

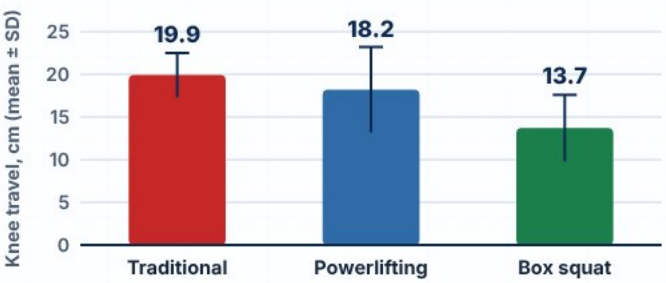


B · Hips back
≈78 N·m at hip



C · Box squat
Depth limit

A box shortens forward knee travel



Forward knee travel during lowering at 70% 1RM, 12 powerlifters. Swinton et al. (2012).

Decision pathway

1. **DOSE DEPTH**
   Set a box just above the depth where pain starts, and lower it as symptoms allow.
2. **SHARE THE LOAD**
   Sit the hips back to move effort to the hip while the front of the thigh settles.
3. **MONITOR**
   Judge progress by symptoms during and the day after, not by form rules alone.

NOT RECOMMENDED

Banning knee travel past the toes for everyone, or squatting through sharp pain.

SEEK ASSESSMENT IF

The knee swells after squatting, locks or gives way, pain persists at rest or at night, or a sudden loss of knee straightening.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Seki, K., Nagano, T., Aoyama, K., & Morioka, Y. (2023). Squat and countermovement vertical jump dynamics using knee dominant or hip dominant strategies. *Journal of Human Kinetics, 86*, 63–71. https://doi.org/10.5114/jhk/159285

Swinton, P. A., Lloyd, R., Keogh, J. W. L., Agouris, I., & Stewart, A. D. (2012). A biomechanical comparison of the traditional squat, powerlifting squat and box squat. *Journal of Strength and Conditioning Research, 26*(7), 1805–1816.

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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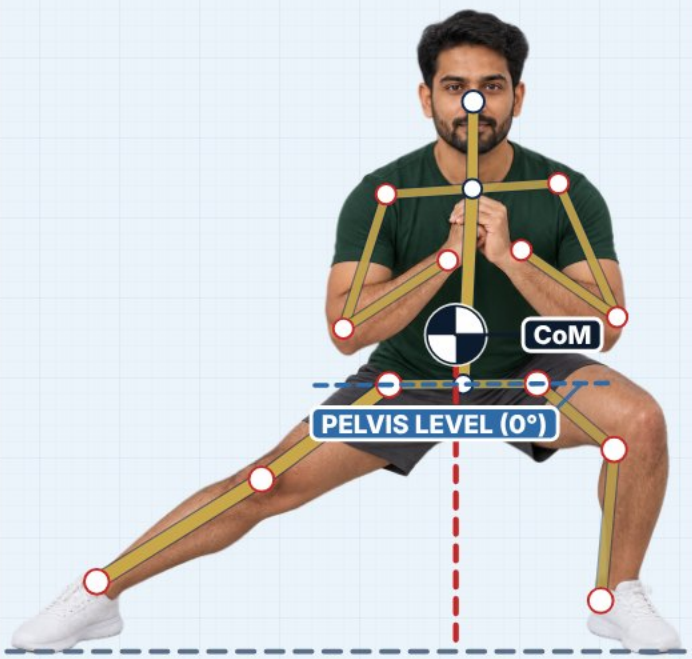
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GROIN STRAIN: ADDUCTOR INJURY IN CHANGE-OF-DIRECTION SPORTS

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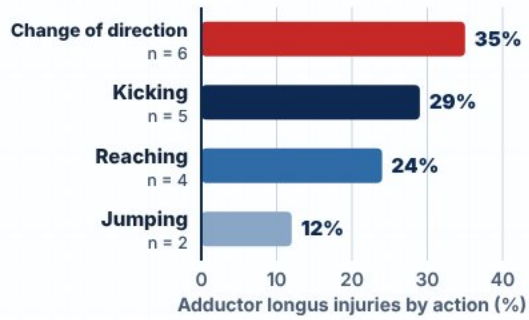
A · SIDE LUNGE, FRONT



Side lunge: the straight leg's adductors are long

- Lateral lunge with one knee bent and the other leg straight out to the side, pelvis level (**0°**): the straight leg is abducted, so its adductors are lengthened while they control the movement.
- On video, change of direction was the commonest action at the moment of an adductor longus injury, followed by kicking, reaching and jumping.

Cutting leads, kicking follows



Video analysis of 17 acute adductor longus injuries in professional male football. Serner et al. (2019).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Pelvis line from the two hip landmarks in the front view. Educational, not diagnostic.

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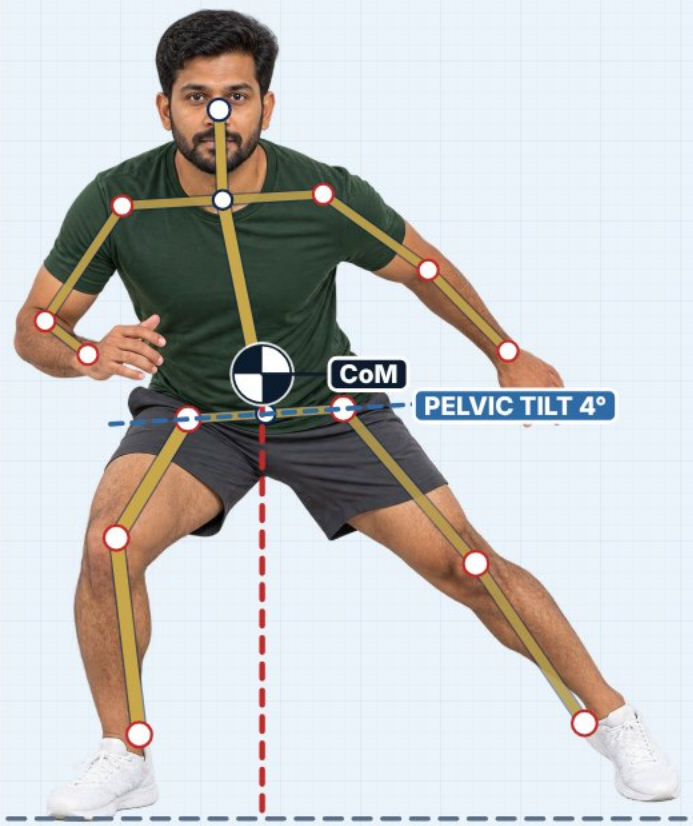
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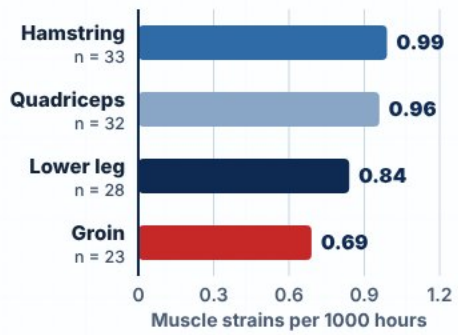
B · CUTTING STEP, FRONT



Plant wide, push hard

- Change-of-direction step, one foot planted wide and the body pushing away from it (pelvis **4°** off level): the planted leg's adductors must brake and redirect the body while lengthened.
- In one professional club over four seasons, groin strains were the least frequent of four muscle regions, but they still recurred often.

Fewest strains, not the least trouble



188 muscle strains, one professional French club, 4 seasons; 44 (23.4%) were re-injuries. Carling et al. (2011).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Pelvis line from the two hip landmarks in the front view. Educational, not diagnostic.

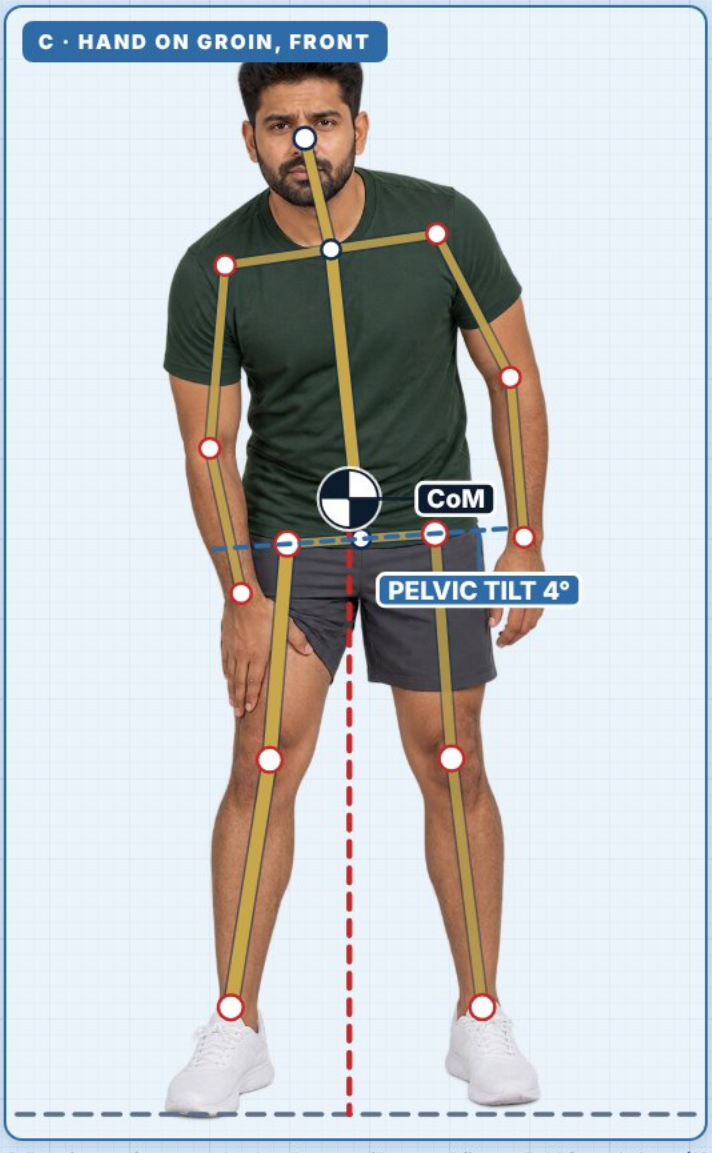
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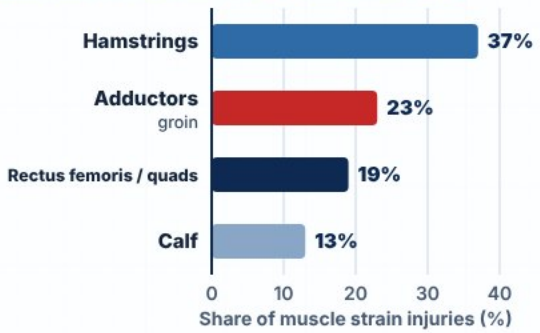


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Inner-thigh pain near the pubic bone

- Standing with a hand on the inner thigh near the groin (pelvis **4°** off level): sudden pain here during cutting, kicking or reaching is the typical story of an adductor strain.
- In professional football the adductors were the second most commonly strained muscle group after the hamstrings, ahead of the rectus femoris and quadriceps and the calf.

Adductors: second only to hamstrings



UEFA professional football cohort, as summarised by Ishøi et al. (2020).

Myth: "A groin strain is just a minor tweak." Groin re-occurrences kept players out longest of four regions in one club.

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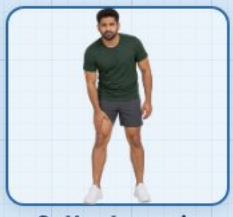
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A · Side lunge
Adductors long

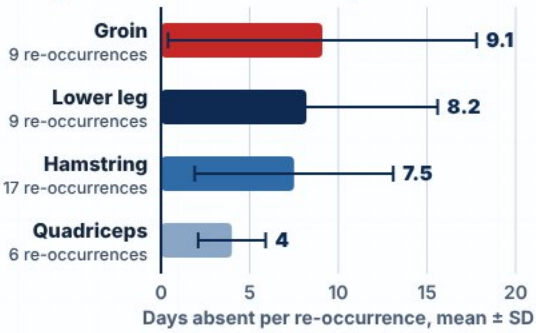


B · Cutting step
Brake and redirect



C · Hand on groin
Inner-thigh pain

Groin re-injuries cost the most days



Muscle strain re-occurrences, one professional club, 4 seasons. Carling et al. (2011).

Decision pathway

1. **EXAMINE**
   Confirm an adductor source: palpation, squeeze tests and resisted adduction.
2. **LOAD**
   Progress adductor strengthening from squeezes to lengthened, faster work.
3. **RETURN**
   Reintroduce cutting and kicking step by step; prevention includes adductor strength work.

NOT RECOMMENDED

Resting a groin strain then returning straight to full-speed cutting and kicking.

SEEK ASSESSMENT IF

A pop with sudden severe pain and bruising high on the inner thigh, difficulty walking, fever, night pain, or a lump on coughing.

REFERENCES (APA 7)

Carling, C., Le Gall, F., & Orhant, E. (2011). A four-season prospective study of muscle strain reoccurrences in a professional football club. Research in Sports Medicine. https://doi.org/10.1080/15438627.2011.556494

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Ishøi, L., Krommes, K., Husted, R. S., Juhl, C. B., & Thorborg, K. (2020). Diagnosis, prevention and treatment of common lower extremity muscle injuries in sport – grading the evidence: A statement paper commissioned by the Danish Society of Sports Physical Therapy (DSSF). *British Journal of Sports Medicine, 54*(9), 528–537. https://doi.org/10.1136/bjsports-2019-101228

Serner, A., Mosler, A. B., Tol, J. L., Bahr, R., & Weir, A. (2019). Mechanisms of acute adductor longus injuries in male football players: A systematic visual video analysis. *British Journal of Sports Medicine, 53*(3), 158–164. https://doi.org/10.1136/bjsports-2018-099246

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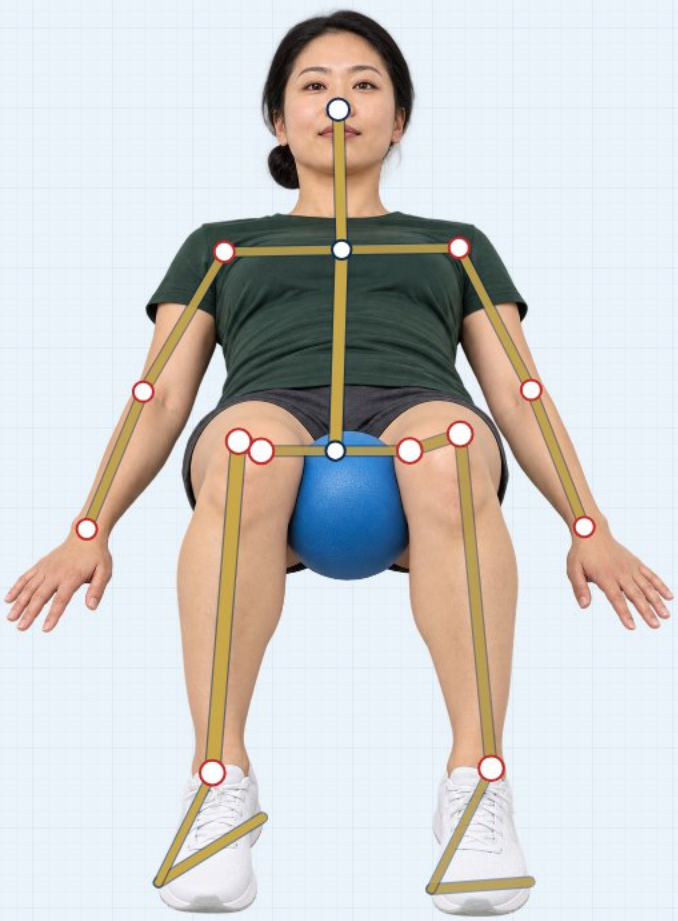
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ADDUCTOR LONGUS PAIN: THE MOST COMMONLY INJURED GROIN MUSCLE

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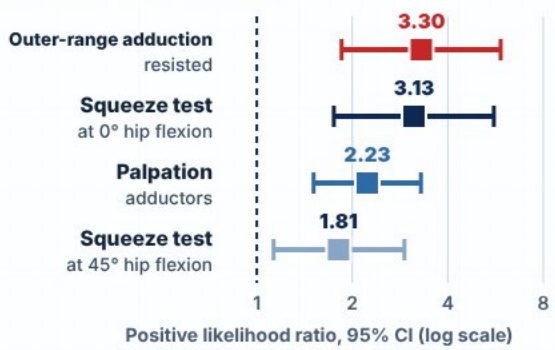
A · BALL SQUEEZE, FRONT



Squeeze: test and first exercise

- Reclined with both knees bent, squeezing a ball between the knees: an isometric adduction that can be graded by effort, used both to provoke symptoms and as early loading.
- Positive squeeze and resisted-adduction tests support an MRI-confirmed adductor injury but do not prove it; about one in five positive tests had no injury on MRI.

Tests that raise the odds



81 athletes with acute groin injury, MRI reference; pre-test probability 57%. Ishøi et al. (2020).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Skeleton only; no angles quoted for this view. Educational, not diagnostic.

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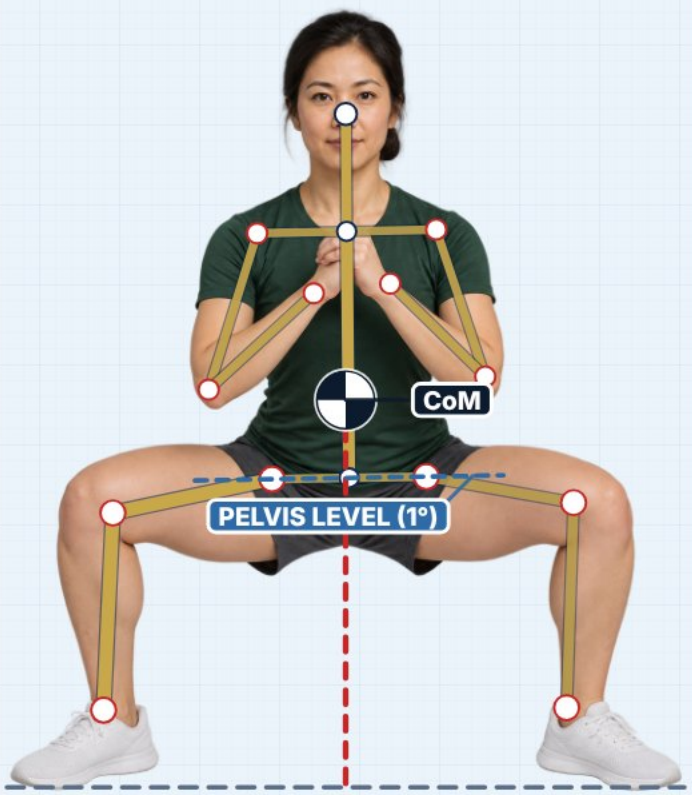
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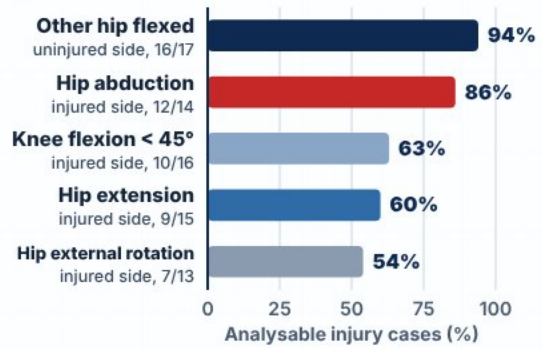
B · SUMO SQUAT, FRONT



Wide stance approaches the injury position

- Wide sumo squat with the toes out and thighs near parallel, pelvis level (**1°**): both hips are abducted and externally rotated, so the adductors work in a lengthened range.
- On video, the injured hip was usually abducted and often extended when the injury occurred: the muscle was long and then asked to contract quickly.

Long muscle, sudden load



17 acute adductor longus injuries in professional male footballers; positions agreed by a five-person panel. Serner et al. (2019).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Pelvis line from the two hip landmarks in the front view. Educational, not diagnostic.

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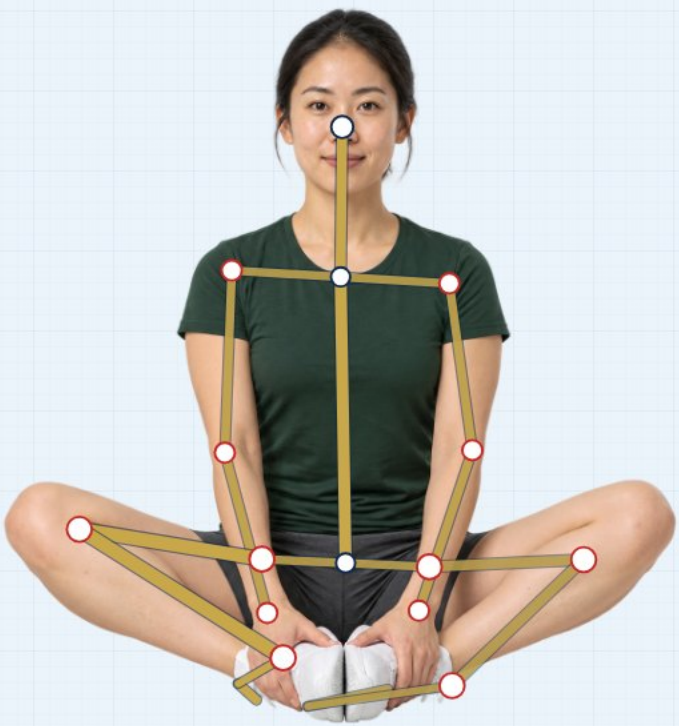
BIOMECHANICS IS A FORCE-GOVERNED DECISION SYSTEM – NOT A POSTURE MODEL.

INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

ADDUCTOR LONGUS PAIN: THE MOST COMMONLY INJURED GROIN MUSCLE

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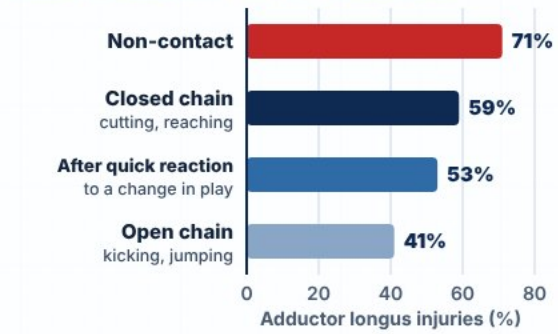
C · BUTTERFLY SIT, FRONT



Butterfly: a gentle lengthened position

- Sitting with the soles together and the knees falling out: the hips are flexed, abducted and externally rotated, a low-load way to explore adductor length once acute pain settles.
- Most injuries were non-contact, in both foot-planted and swinging-leg actions, so rehabilitation needs to cover cutting and kicking demands.

Planted and swinging legs both fail



Video analysis, 17 injuries; closed and open chain sum to 100%. Serner et al. (2019).

Myth: "Just stretch tight adductors." Injuries happened with the muscle already long; the authors recommend building rapid-loading capacity in that position.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Skeleton only; no angles quoted for this seated floor pose. Educational, not diagnostic.

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A · Ball squeeze
Isometric test

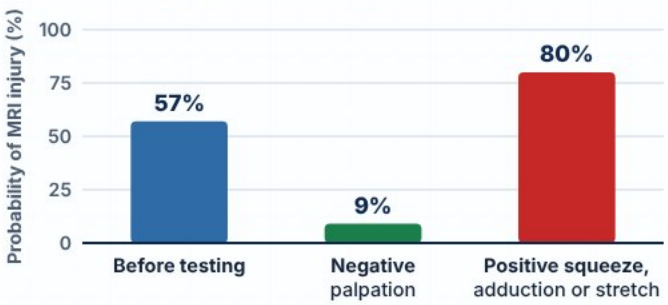


B · Sumo squat
Lengthened range



C · Butterfly sit
Gentle length

A pain-free palpation nearly rules it out



Post-test probabilities from a 57% pre-test probability; positive tests 80–81%. Ishøi et al. (2020).

Decision pathway

1. **PALPATE**
   If the adductors are not tender to touch, an acute adductor injury is unlikely.
2. **SQUEEZE**
   Start with graded isometric squeezes, then load the muscle in wider, longer positions.
3. **SPEED UP**
   Progress to faster, multi-plane work before cutting and kicking.

NOT RECOMMENDED

Relying on stretching alone, or returning to full-speed cutting while squeezes still hurt.

SEEK ASSESSMENT IF

A pop with severe pain, extensive bruising or a gap high on the inner thigh, night pain, fever, or pain on coughing or straining.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Ishøi, L., Krommes, K., Husted, R. S., Juhl, C. B., & Thorborg, K. (2020). Diagnosis, prevention and treatment of common lower extremity muscle injuries in sport – grading the evidence: A statement paper commissioned by the Danish Society of Sports Physical Therapy (DSSF). *British Journal of Sports Medicine, 54*(9), 528–537. https://doi.org/10.1136/bjsports-2019-101228

Serner, A., Mosler, A. B., Tol, J. L., Bahr, R., & Weir, A. (2019). Mechanisms of acute adductor longus injuries in male football players: A systematic visual video analysis. *British Journal of Sports Medicine, 53*(3), 158–164. https://doi.org/10.1136/bjsports-2018-099246

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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COPENHAGEN ADDUCTION EXERCISE: PREVENTING GROIN INJURY

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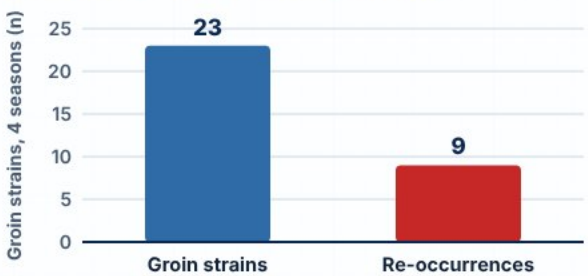
A · BENCH SIDE PLANK, FRONT



Bench plank: the adductors hold the body

- Side plank on the forearm, top lower leg resting on a bench and the bottom knee bent beneath: the top-leg adductors help lift and hold the body. The easiest version places the bench under the knee.
- The target is costly: in one professional club over four seasons there were 23 groin strains and 9 re-occurrences, which had the longest mean absence of four regions (9.1 days).

What the exercise aims to prevent



One professional French football club; 0.69 groin strains per 1000 h. Carling et al. (2011).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmarks drawn: pose detection is unreliable for side-lying planks. Educational, not diagnostic.

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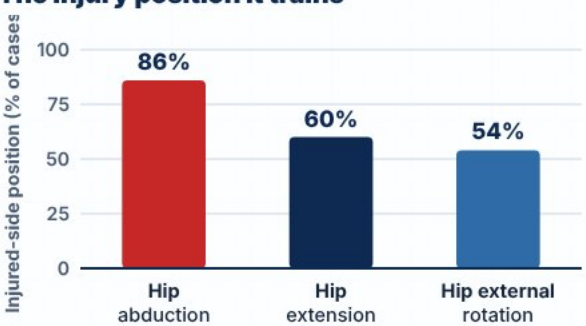
B · LONG-LEVER PLANK, FRONT



Long lever: more demand, same target

- Ankle on the bench with the bottom leg under it: moving the support from the knee to the ankle lengthens the lever, so by simple mechanics the adductors must work harder (not measured in the studies here).
- Adductor longus injuries happened with the hip abducted and often extended, the lengthened range this exercise works through.

The injury position it trains



17 videoed adductor longus injuries, professional male football; 71% non-contact. Serner et al. (2019).

Key point: progress from short to long lever over weeks; the lever, not added weight, is the main dose dial.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmarks drawn: pose detection is unreliable for side-lying planks. Educational, not diagnostic.

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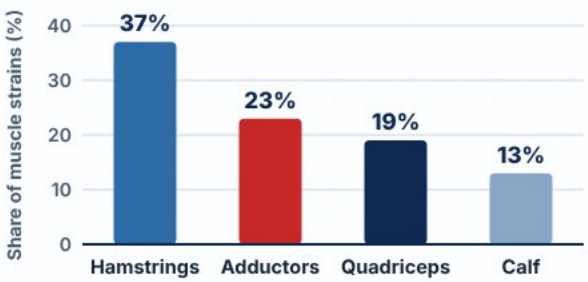
C · SIDE-LYING ADDUCTION



Side-lying adduction: the first step

- Lying on his side, top leg bent with the foot planted in front, the straight bottom leg lifted off the floor: the lowest-load adduction exercise, a starting point before the bench versions.
- Adductors were the second most commonly strained muscle group in professional football, so they merit specific strength work, not stretching alone.

Adductors: a frequent target



Quadriceps includes rectus femoris; professional football cohort as summarised by Ishøi et al. (2020).

Myth: "Groin injury prevention is just about stretching." The best-graded preventive evidence was for adductor strengthening.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmarks drawn: pose detection is unreliable for side-lying poses. Educational, not diagnostic.

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A · Bench plank
Bottom knee bent

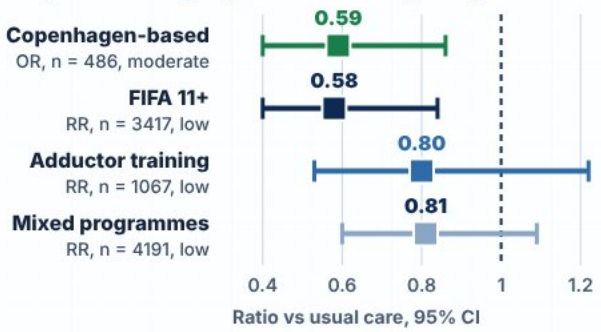


B · Long lever
Higher demand



C · Side-lying
First step

Strength-based programmes cut groin problems



Copenhagen trial counted all groin problems, not only strains; quality of evidence shown. Ishøi et al. (2020).

Decision pathway

1. **START LOW**
   Begin with side-lying adduction, then the short-lever plank with the knee on the bench.
2. **LENGTHEN**
   Move to the long lever over weeks as the effort becomes manageable.
3. **KEEP IT UP**
   Run it within the warm-up through the season, alongside a programme such as the FIFA 11+.

NOT RECOMMENDED

Using the exercise to train through an undiagnosed groin injury.

SEEK ASSESSMENT IF

Sharp groin pain during the exercise, pain that persists the next day, or groin pain on coughing or sneezing.

REFERENCES (APA 7)

Carling, C., Le Gall, F., & Orhant, E. (2011). A four-season prospective study of muscle strain reoccurrences in a professional football club. Research in Sports Medicine. https://doi.org/10.1080/15438627.2011.556494

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Ishøi, L., Krommes, K., Husted, R. S., Juhl, C. B., & Thorborg, K. (2020). Diagnosis, prevention and treatment of common lower extremity muscle injuries in sport – grading the evidence: A statement paper commissioned by the Danish Society of Sports Physical Therapy (DSSF). *British Journal of Sports Medicine, 54*(9), 528–537. https://doi.org/10.1136/bjsports-2019-101228

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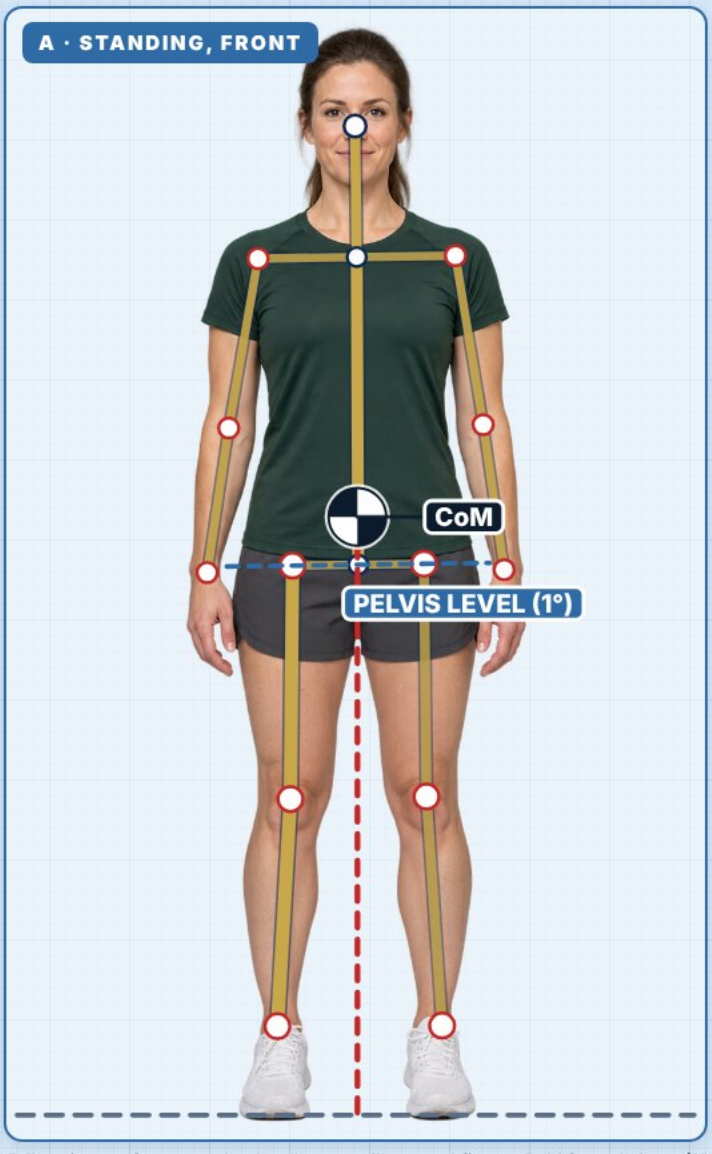
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INNER THIGH PAIN: MUSCLE, TENDON, HIP JOINT OR HERNIA?

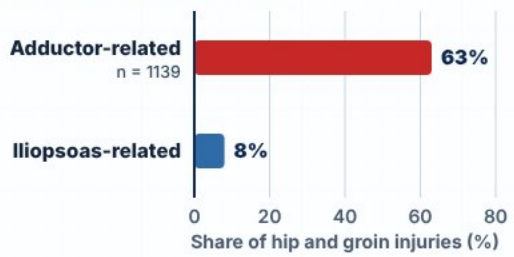
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The groin is a crossroads

- Relaxed standing with the pelvis level (**1°**): adductors, iliopsoas, the hip joint, the pubic bone and the inguinal canal all lie within a hand's width of each other.
- The Doha agreement therefore labels groin pain by examination findings — adductor-, iliopsoas-, inguinal-, pubic- or hip-related — not by where it hurts.

Adductors lead in football



1812 time-loss hip and groin injuries, 47 professional men's teams; pubic-, inguinal- and hip-related approximately 3–4% each. Werner et al. (2019).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Pelvis line from the two hip landmarks in the front view. Educational, not diagnostic.

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B · KNEE ACROSS BODY, FRONT



Hip provocation rules out, not in

- One knee hugged up and across towards the opposite shoulder: hip flexion with adduction, the position used in FADIR-type tests.
- Pooled sensitivity is very high, so a pain-free test makes hip-joint pathology less likely; a painful test only screens and does not confirm it.

Sensitive screening tests



Tests for femoroacetabular impingement or labral tear; 21 articles, 9 meta-analysed; specificity not reported. Reiman et al. (2015).

Key point: the consensus is that the hip should always be considered as a possible source of groin pain.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmarks drawn: this pose is not suitable for 2-D angle estimates. Educational, not diagnostic.

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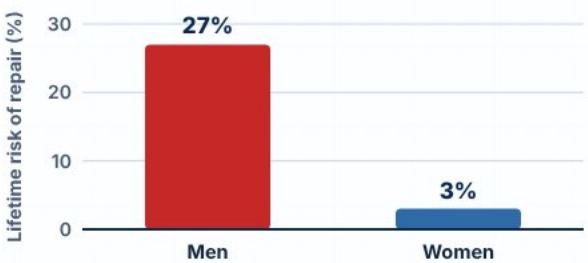
C · COUGH TEST, FRONT



Cough pain: a hernia question

- Coughing into her elbow with a hand over the groin: a cough raises abdominal pressure, so pain or a bulge here points the examiner to the inguinal canal.
- Cough pain with a palpable lump is a hernia question for a surgeon; canal tenderness without a lump fits inguinal-related groin pain.

Hernia repair is common in men



30 675 inguinal hernia repairs, Oxford Record Linkage Study, 1976–1986; 91% of operations in males. Primatesta & Goldacre (1996).

Myth: "Groin pain is always a strain — or always a hernia." One athlete in three has more than one painful entity.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Skeleton and CoM only; no angles quoted for this pose. Educational, not diagnostic.

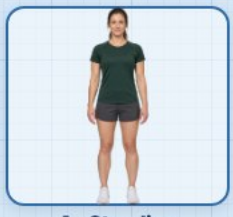
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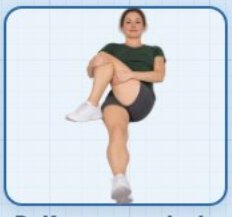
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A · Standing
Pelvis level

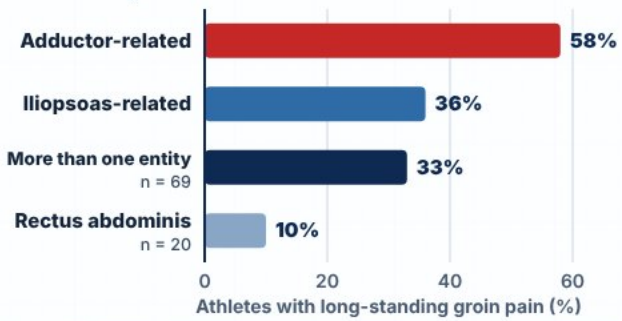


B · Knee across body
Hip screen



C · Cough test
Hernia screen

Often "and", not "or"



207 athletes, standardised examination; categories overlap and do not sum to 100%. Hölmich (2007).

Decision pathway

1. **EXAMINE**
   Classify by history and examination: adductor, iliopsoas, inguinal, pubic or hip-related, plus other causes.
2. **SCREEN THE HIP**
   Check passive range, FABER and FADIR; use a pain-free test to rule hip pathology out.
3. **TREAT THE ENTITY**
   Load the structure found; a minimally symptomatic hernia in a man can be watched safely.

NOT RECOMMENDED

Labelling all groin pain a strain, or relying on imaging alone without an examination.

SEEK ASSESSMENT IF

A painful or irreducible groin lump, fever, night pain, inability to bear weight, or a child or teenager with a limp.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Hölmich, P. (2007). Long-standing groin pain in sportspeople falls into three primary patterns, a "clinical entity" approach: A prospective study of 207 patients. *British Journal of Sports Medicine, 41*(4), 247–252. https://doi.org/10.1136/bjsm.2006.033373

Primatesta, P., & Goldacre, M. J. (1996). Inguinal hernia repair: Incidence of elective and emergency surgery, readmission and mortality. *International Journal of Epidemiology, 25*(4), 835–839. https://doi.org/10.1093/ije/25.4.835

Reiman, M. P., Goode, A. P., Cook, C. E., Hölmich, P., & Thorborg, K. (2015). Diagnostic accuracy of clinical tests for the diagnosis of hip femoroacetabular impingement/labral tear: A systematic review with meta-analysis. *British Journal of Sports Medicine, 49*(12), 811. https://doi.org/10.1136/bjsports-2014-094302

Tumtavitikul, S. (2017). Highlights from the international guidelines for groin hernia management. *Annals of Laparoscopic and Endoscopic Surgery, 2*(11), 161. https://doi.org/10.21037/ales.2017.10.07

Weir, A., Brukner, P., Delahunt, E., Ekstrand, J., Griffin, D., Khan, K. M., Lovell, G., Meyers, W. C., Muschaweck, U., Orchard, J., Paajanen, H., Philippon, M., Reboul, G., Robinson, P., Schache, A. G., Schilders, E., Serner, A., Silvers, H., Thorborg, K., … Hölmich, P. (2015). Doha agreement meeting on terminology and definitions in groin pain in athletes. *British Journal of Sports Medicine, 49*(12), 768–774. https://doi.org/10.1136/bjsports-2015-094869

Werner, J., Hägglund, M., Ekstrand, J., & Waldén, M. (2019). Hip and groin time-loss injuries decreased slightly but injury burden remained constant in men's professional football: The 15-year prospective UEFA Elite Club Injury Study. *British Journal of Sports Medicine, 53*(9), 539–546. https://doi.org/10.1136/bjsports-2017-097796

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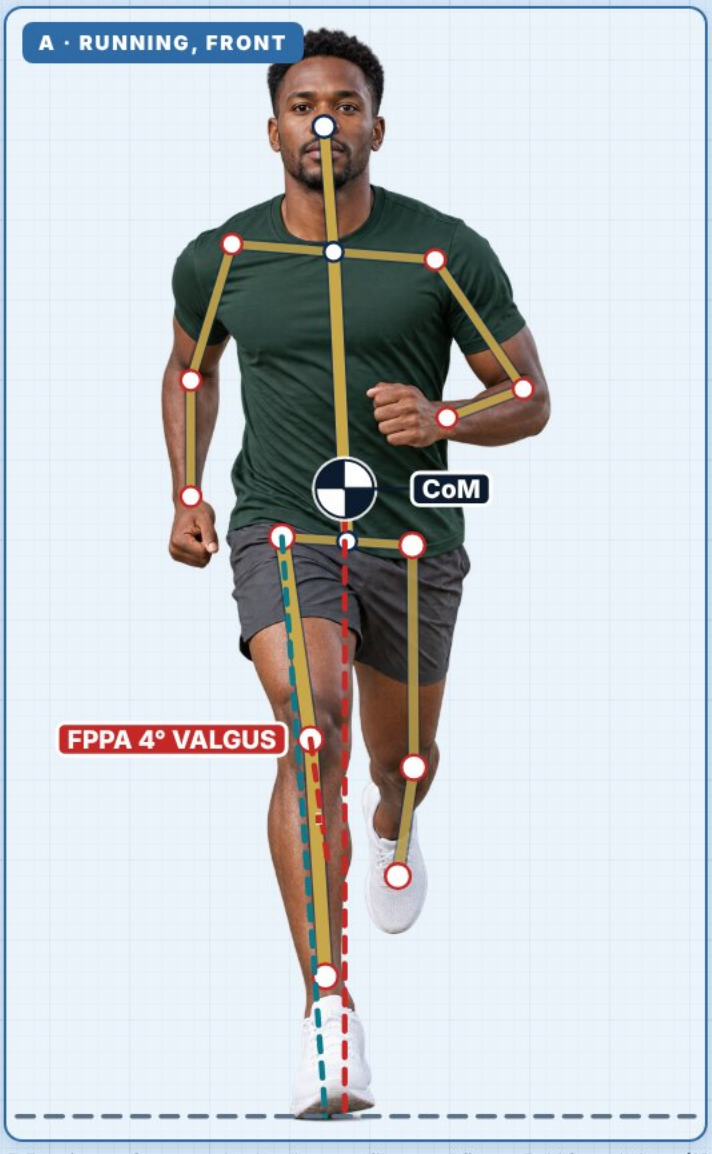
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IT BAND PAIN: WHY STRETCHING THE BAND RARELY FIXES IT

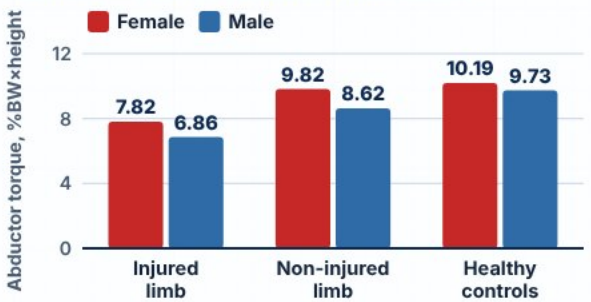
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Landing loads the outer knee

- Running towards the camera, the landing knee sits **4°** off the hip–ankle line: each step asks the hip abductors to hold the pelvis and thigh in line.
- Iliotibial band syndrome causes outer-knee pain near the femoral epicondyle and accounts for about one tenth of running injuries.

Weaker abductors on the painful side



Group means; 24 distance runners with ITBS and 30 healthy runners; all differences P < 0.05. Fredericson et al. (2000).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Front-view knee angle (FPPA) from hip, knee and ankle landmarks of the landing leg. Educational, not diagnostic.

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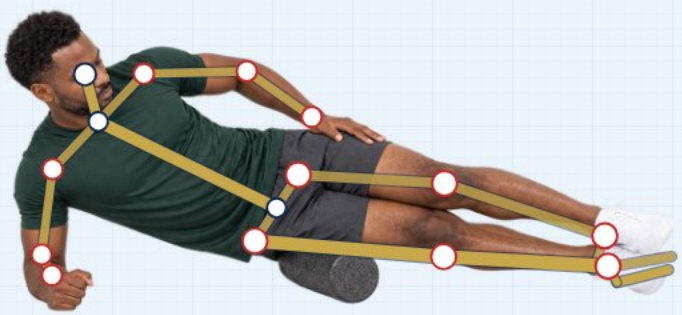
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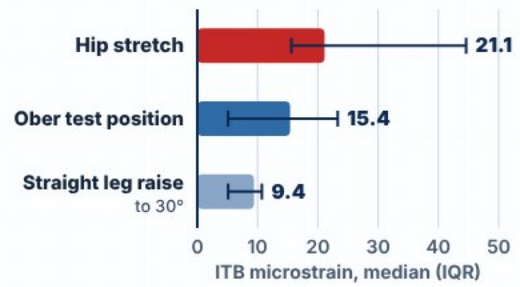
B · FOAM ROLLING, SIDE



The band barely lengthens

- Side-lying on a foam roller under the outer thigh, propped on the forearm: rolling may change how the band feels, but anatomy shows it is anchored to the femur.
- In living runners the band lengthened by less than 0.5% during hip abduction; cadaver stretches strained it only in the microstrain range.

Stretches barely strain the band



Strain gauges on the ITB of five unembalmed cadavers. Falvey et al. (2010).

Myth: "Roll the IT band until it releases." Stretching is unlikely to change its length or mechanical properties.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Skeleton only: lying poses are not measured. Educational, not diagnostic.

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INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

IT BAND PAIN: WHY STRETCHING THE BAND RARELY FIXES IT

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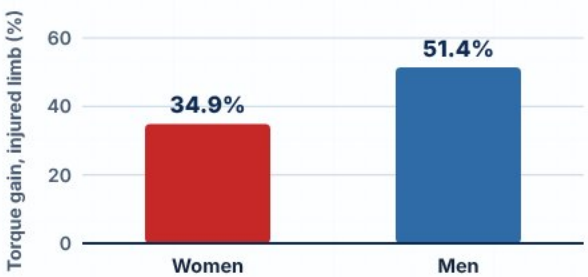
C · SIDE PLANK LEG LIFT, FRONT



Train the hip, not the band

- Side plank on the forearm with the top leg lifted: the hip abductors on both sides work against body weight, targeting the deficit seen in runners with ITBS.
- After six weeks of abductor training, 22 of 24 runners were pain-free and back running; a case series shows association, not proof of cause.

Strength rose with rehab



Change in injured-limb hip abductor torque after a 6-week programme; 14 women, 10 men. Fredericson et al. (2000).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmarks drawn: side-plank poses are not measured. Educational, not diagnostic.

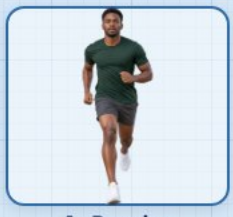
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A · Running
Knee 4° off line



B · Foam rolling
Feel, not length



C · Side plank lift
Abductor load

Conservative care usually helps



Reported ranges, 13 studies, 201 runners, 2–8 weeks of treatment; small, mostly low-level evidence. Sanchez-Alvarado et al. (2024).

Decision pathway

1. **CALM**
   Reduce the running volume and downhill work that provoke outer-knee pain, without stopping all activity.
2. **STRENGTHEN**
   Progress hip abductor work such as side planks and single-leg control.
3. **RETRAIN**
   Review gait: greater hip adduction and knee internal rotation are linked with ITBS.

NOT RECOMMENDED

Aggressive stretching or rolling of the band as the main treatment.

SEEK ASSESSMENT IF

Locking, giving way, marked swelling, a twisting injury, or pain at rest or at night that does not settle.

REFERENCES (APA 7)

Aderem, J., & Louw, Q. A. (2015). Biomechanical risk factors associated with iliotibial band syndrome in runners: A systematic review. *BMC Musculoskeletal Disorders, 16*, 356. https://doi.org/10.1186/s12891-015-0808-7

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Fairclough, J., Hayashi, K., Toumi, H., Lyons, K., Bydder, G., Phillips, N., Best, T. M., & Benjamin, M. (2006). The functional anatomy of the iliotibial band during flexion and extension of the knee: Implications for understanding iliotibial band syndrome. *Journal of Anatomy, 208*(3), 309–316. https://doi.org/10.1111/j.1469-7580.2006.00531.x

Falvey, E. C., Clark, R. A., Franklyn-Miller, A., Bryant, A. L., Briggs, C., & McCrory, P. R. (2010). Iliotibial band syndrome: An examination of the evidence behind a number of treatment options. *Scandinavian Journal of Medicine & Science in Sports, 20*(4), 580–587. https://doi.org/10.1111/j.1600-0838.2009.00968.x

Fredericson, M., Cookingham, C. L., Chaudhari, A. M., Dowdell, B. C., Oestreicher, N., & Sahrmann, S. A. (2000). Hip abductor weakness in distance runners with iliotibial band syndrome. *Clinical Journal of Sport Medicine, 10*(3), 169–175. https://doi.org/10.1097/00042752-200007000-00004

Friede, M. C., Innerhofer, G., Fink, C., et al. (2022). Conservative treatment of iliotibial band syndrome in runners: Are we targeting the right goals? *Physical Therapy in Sport, 54*, 44–52.

Sanchez-Alvarado, A., Bokil, C., Cassel, M., & Engel, T. (2024). Effects of conservative treatment strategies for iliotibial band syndrome on pain and function in runners: A systematic review. Frontiers in Sports and Active Living, 6. https://doi.org/10.3389/fspor.2024.1386456

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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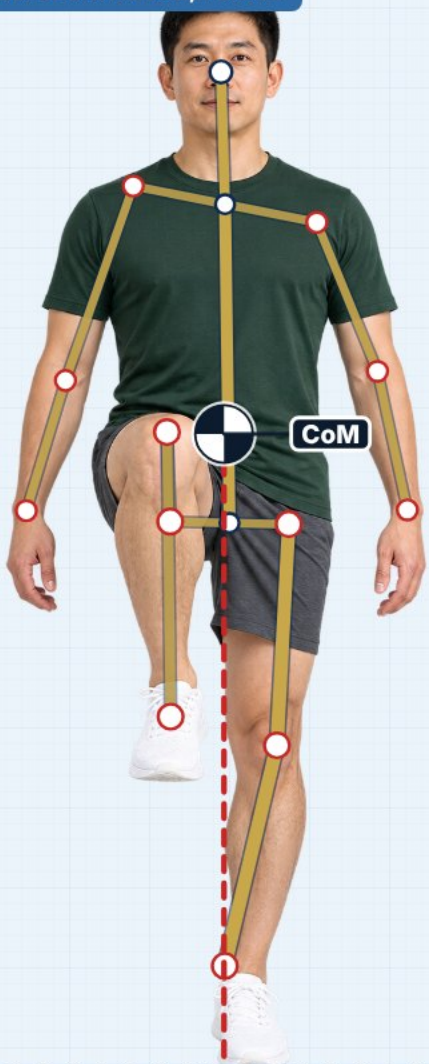
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OUTER THIGH PAIN: GLUTEAL TENDON, IT BAND OR REFERRED PAIN?

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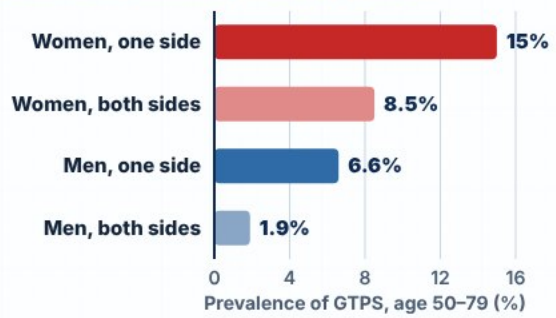
A · SINGLE-LEG STANCE, FRONT



One leg loads the side of the hip

- Standing on one leg with the other knee lifted: the stance-side gluteus medius and minimus hold the pelvis, compressing their tendons at the greater trochanter.
- Lateral hip pain within 30 s of single-leg stance was 100% specific for MRI-confirmed gluteal tendinopathy in 65 patients, though the sample was small.

Common in midlife, more in women



3026 community adults, MOST Study; female sex OR 3.37 (95% CI 2.67–4.25). Segal et al. (2007).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Lifted-leg hip landmark corrected by hand; no angles quoted. Educational, not diagnostic.

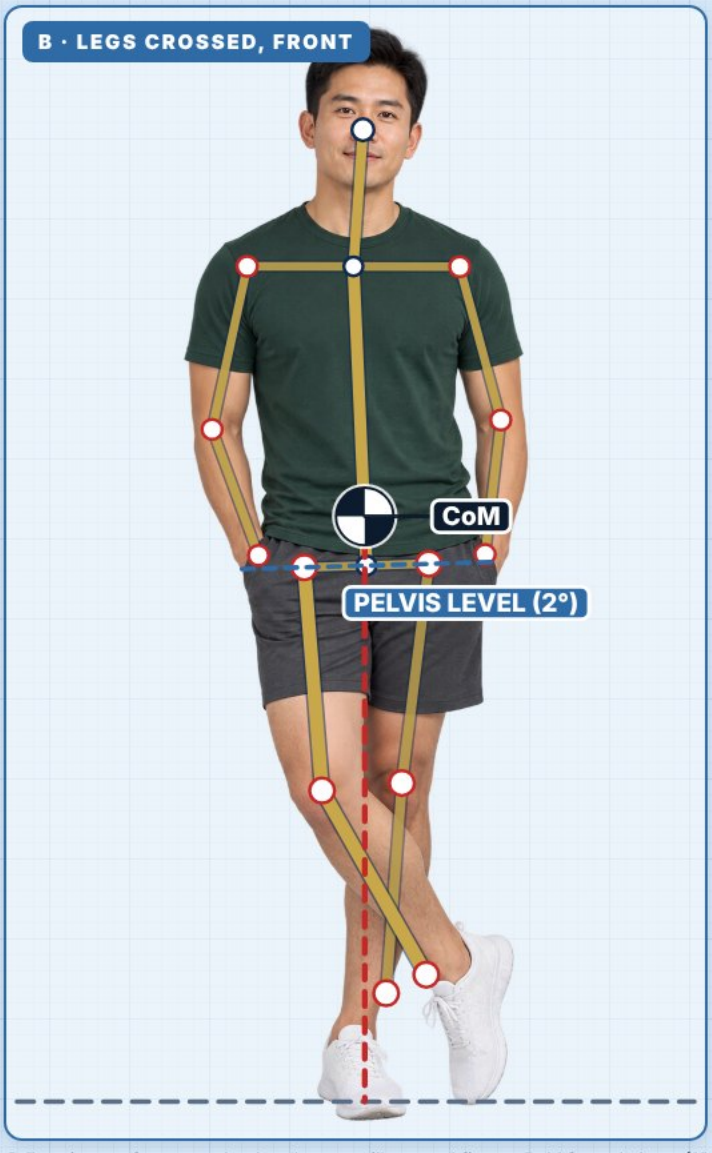
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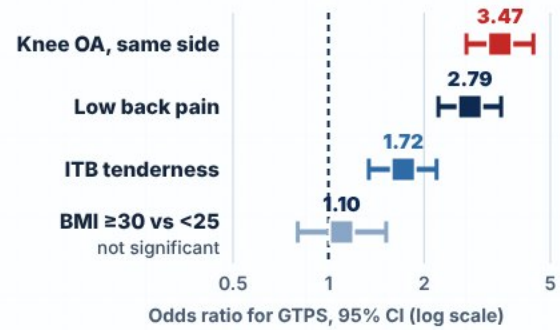
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Crossing pulls the tendons tight

- Standing with the legs crossed, pelvis near level (**2°**): the hip drops into adduction, which draws the gluteal tendons and the IT band across the trochanter.
- GTPS travels with back pain and knee arthritis as well as ITB tenderness, so the pain may be local, coexisting or referred.

Back and knee travel with it



Multivariate model, 3026 adults aged 50–79; cross-sectional associations, not causes. Segal et al. (2007).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Pelvis line from the two hip landmarks in the front view. Educational, not diagnostic.

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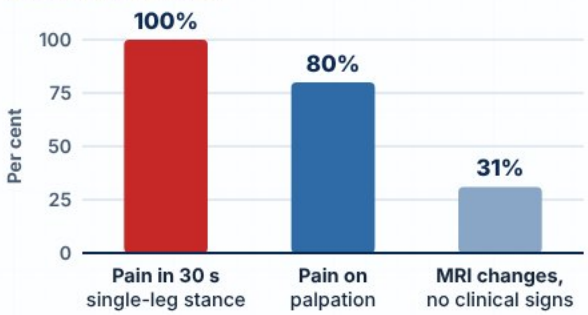
C · SIDE-LYING, FRONT



Night pain and the top knee

- Lying on his side in bed with the top knee dropped across the body: the top hip rests in adduction for hours, holding the gluteal tendons compressed against the trochanter.
- Palpation helps rule out; single-leg stance helps rule in. A third had MRI tendon changes without clinical signs, so scans alone do not name the source.

Tests versus MRI



65 people with lateral hip pain. Specificity (stance), sensitivity (palpation) and share MRI-positive but clinically negative. Grimaldi et al. (2017).

Myth: "It is bursitis, so it needs an injection." Education plus exercise did better at 8 and 52 weeks.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmarks drawn: lying poses are not measured. Educational, not diagnostic.

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A · Single-leg stance
Rule-in test



B · Legs crossed
Hip adducted



C · Side-lying
Night compression

Education plus exercise wins



204 adults with gluteal tendinopathy, randomised; percentages from published counts. Mellor et al. (2018).

Decision pathway

1. **LOCATE**
   Palpate the trochanter and time single-leg stance; screen the lumbar spine and the knee.
2. **OFFLOAD**
   Limit crossing the legs, hanging on one hip and side-lying with the top knee dropped.
3. **LOAD**
   Progress hip abductor strength with education; injection eases pain only in the short term.

NOT RECOMMENDED

Treating a scan finding alone, or repeated injections without an exercise plan.

SEEK ASSESSMENT IF

Night pain unrelated to position, fever, weight loss, a fall with inability to bear weight, or numbness and weakness down the leg.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Grimaldi, A., Mellor, R., Nicolson, P., Hodges, P., Bennell, K., & Vicenzino, B. (2017). Utility of clinical tests to diagnose MRI-confirmed gluteal tendinopathy in patients presenting with lateral hip pain. *British Journal of Sports Medicine, 51*(6), 519–524.

Mellor, R., Bennell, K., Grimaldi, A., Nicolson, P., Kasza, J., Hodges, P., Wajswelner, H., & Vicenzino, B. (2018). Education plus exercise versus corticosteroid injection use versus a wait and see approach on global outcome and pain from gluteal tendinopathy: Prospective, single blinded, randomised clinical trial. *BMJ, 361*, k1662. https://doi.org/10.1136/bmj.k1662

Segal, N. A., Felson, D. T., Torner, J. C., Zhu, Y., Curtis, J. R., Niu, J., Nevitt, M. C., & Multicenter Osteoarthritis Study Group. (2007). Greater trochanteric pain syndrome: Epidemiology and associated factors. *Archives of Physical Medicine and Rehabilitation, 88*(8), 988–992. https://doi.org/10.1016/j.apmr.2007.04.014

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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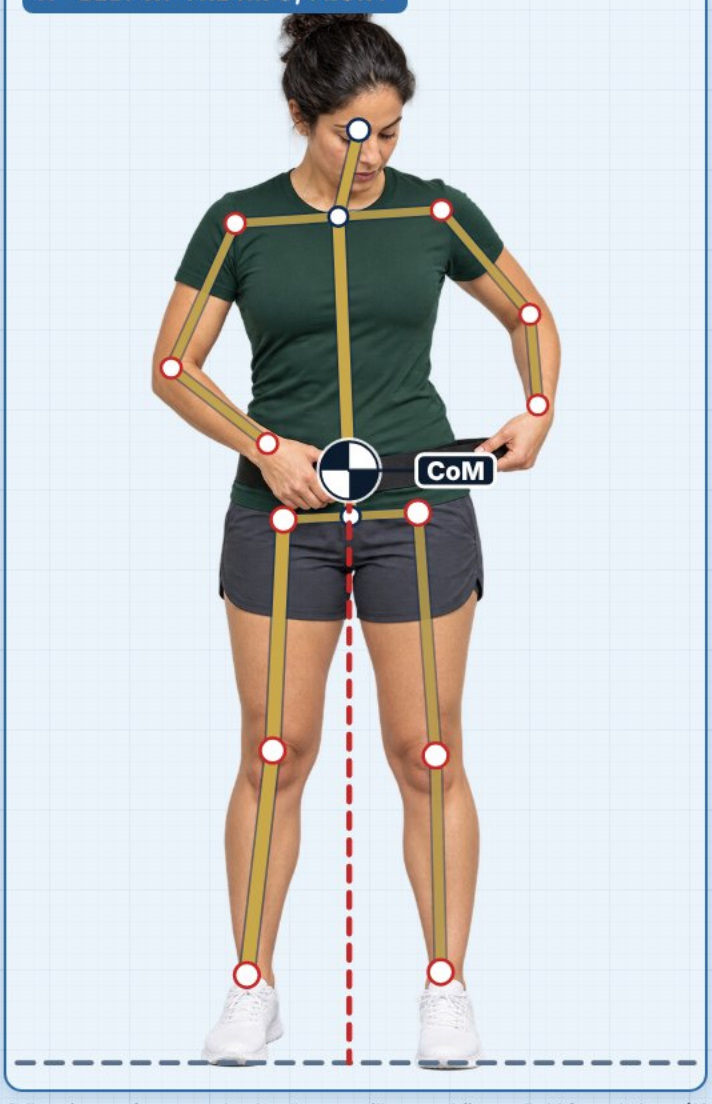
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MERALGIA PARAESTHETICA: BURNING OUTER-THIGH PAIN FROM A NERVE

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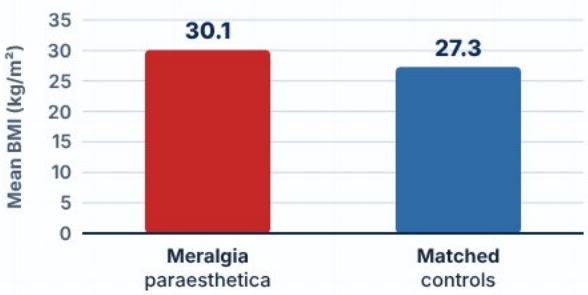
A · BELT AT THE HIPS, FRONT



A tight band over a narrow exit

- Adjusting a wide belt worn low on the hips: the lateral femoral cutaneous nerve leaves the pelvis under the inguinal ligament, just inside the front of the hip bone.
- Waist pressure from tight belts, waistbands or a larger abdomen loads that exit point; obesity and tight garments are recognised risk factors.

Higher body mass in MP



262 patients with MP vs age- and sex-matched controls, Olmsted County, 1990–1999. Parisi et al. (2011).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Skeleton and CoM only; no angles quoted for this pose. Educational, not diagnostic.

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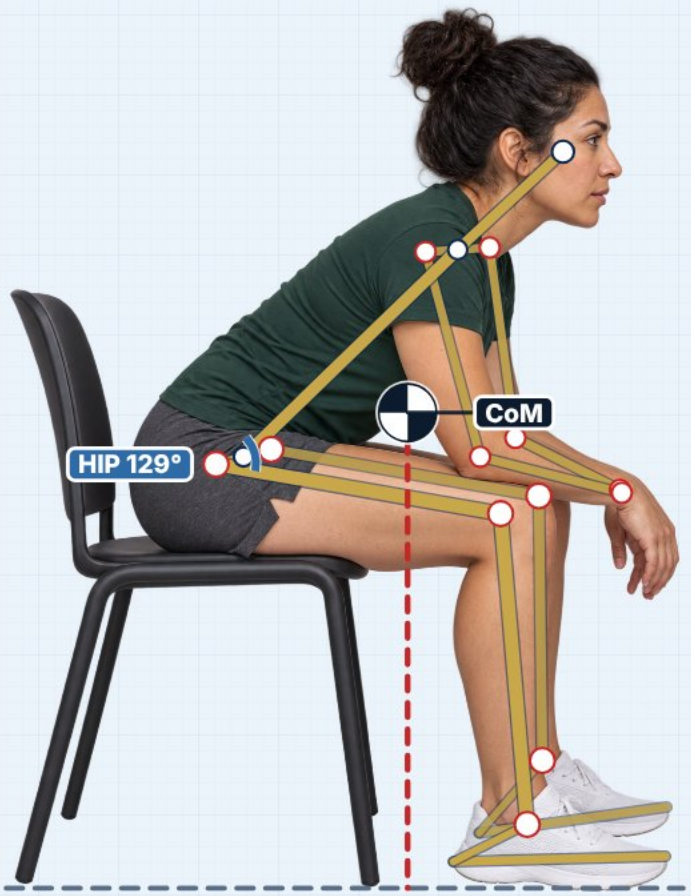
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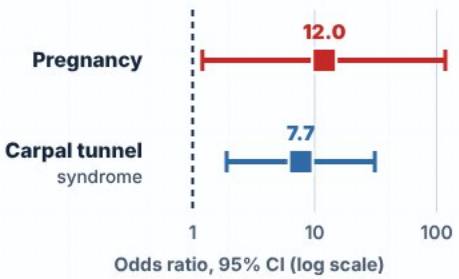
B · SEATED LEAN, SIDE



Flexing the hip slackens the nerve

- Sitting and leaning far forward with the hip flexed **129°**: hip flexion slackens the nerve at the ligament, which is why classic symptoms often ease when sitting.
- Pregnancy and carpal tunnel syndrome were linked with MP, but 79% of cases had no identified cause.

What travels with MP



Dutch general practice, 173 375 patient-years; wide intervals reflect small numbers. Van Slobbe et al. (2004).

Key point: the nerve is purely sensory, so MP causes burning and numbness but no leg weakness.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip angle from pose landmarks in the side view (trunk line to thigh). Educational, not diagnostic.

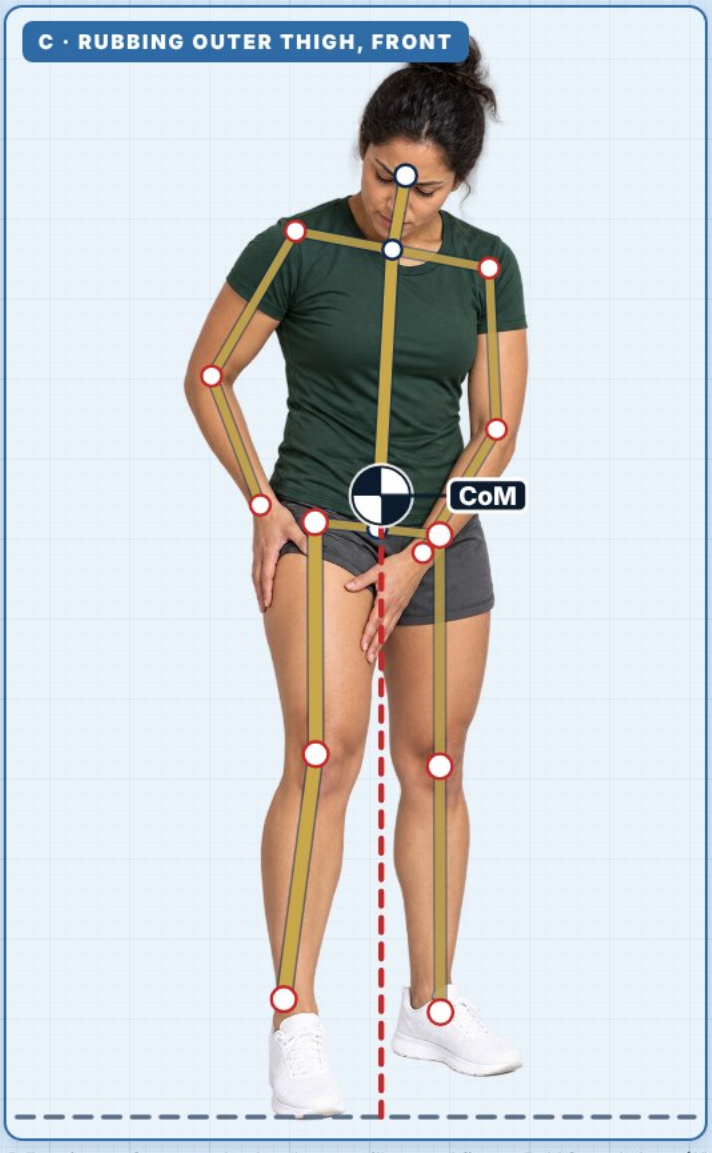
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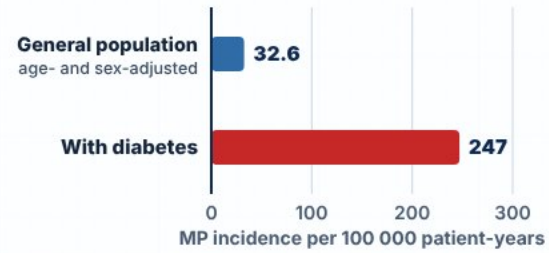
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Burning skin, not a sore muscle

- Rubbing the front-outer thigh: MP typically causes burning, stabbing pain or numbness of the skin in this patch, without muscle tenderness or weakness.
- Incidence was about seven times higher in people with diabetes, and people with MP were twice as likely to develop diabetes.

Diabetes raises the rate



Population-based study, Olmsted County, 1990–1999; 262 patients with MP. Parisi et al. (2011).

Myth: "Burning in the thigh means a slipped disc." Classic MP spares strength and reflexes.

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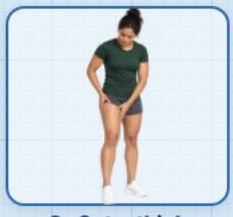
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A · Belt at the hips
Waist pressure

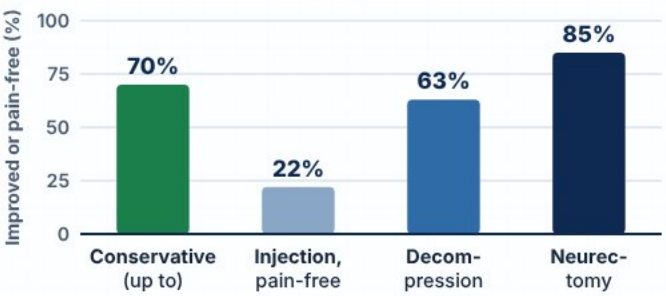


B · Seated lean
Hip 129°



C · Outer thigh
Skin symptoms

Most settle without surgery



Secondary summary of retrospective series and meta-analyses; surgery only for persistent cases. Scholz et al. (2023).

Decision pathway

1. **UNLOAD**
   Loosen belts and waistbands, manage weight and avoid prolonged pressure at the front of the hip.
2. **CONFIRM**
   Check that strength and reflexes are normal; ultrasound or nerve tests if the picture is unclear.
3. **ESCALATE**
   Injection may give short-term relief; surgery is for persistent, disabling cases.

NOT RECOMMENDED

Assuming a disc or muscle problem, or rushing to surgery before conservative care.

SEEK ASSESSMENT IF

Any leg weakness, reflex loss, symptoms spreading from the back or into the inner thigh or groin, or new symptoms after surgery.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Parisi, T. J., Mandrekar, J., Dyck, P. J. B., & Klein, C. J. (2011). Meralgia paresthetica: Relation to obesity, advanced age, and diabetes mellitus. *Neurology, 77*(16), 1538–1542. https://doi.org/10.1212/WNL.0b013e318233b356

Payne, R., Seaman, S., Sieg, E., Langan, S., Harbaugh, K., & Rizk, E. (2017). Evaluating the evidence: Is neurolysis or neurectomy a better treatment for meralgia paresthetica? *Acta Neurochirurgica, 159*(5), 931–936. https://doi.org/10.1007/s00701-017-3136-x

Scholz, C., Hohenhaus, M., Pedro, M. T., Uerschels, A.-K., & Dengler, N. F. (2023). Meralgia paresthetica: Relevance, diagnosis, and treatment. *Deutsches Ärzteblatt International, 120*, 655–661. https://doi.org/10.3238/arztebl.m2023.0170

Van Slobbe, A. M., Bohnen, A. M., Bernsen, R. M. D., Koes, B. W., & Bierma-Zeinstra, S. M. (2004). Incidence rates and determinants in meralgia paresthetica in general practice. *Journal of Neurology, 251*(3), 294–297. https://doi.org/10.1007/s00415-004-0310-x

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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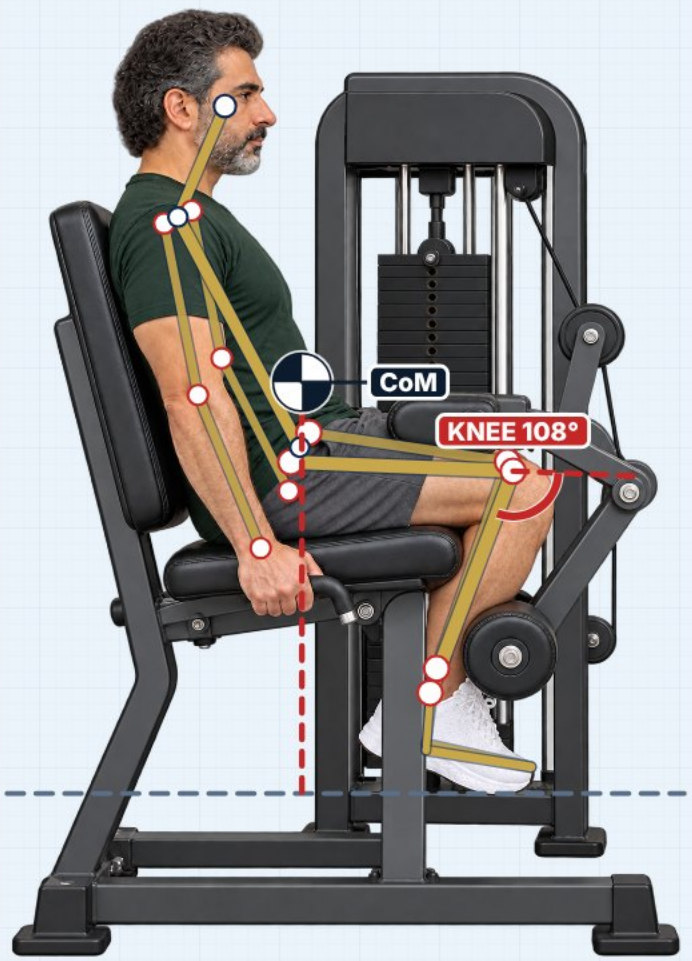
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THIGH MUSCLE IMBALANCE: WHAT THE HAMSTRING-TO-QUADRICEPS RATIO MEANS

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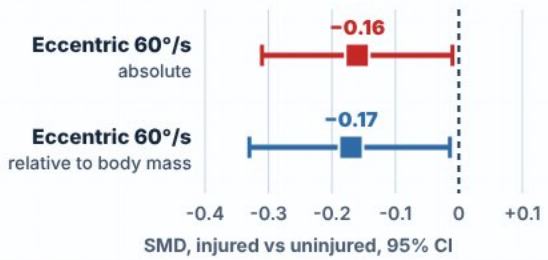
A · SEATED LEG CURL, SIDE



The curl measures the flexors

- Seated leg curl at the end of the pull, knee flexed ≈**108°**: the hamstrings shorten against the pad, the concentric strength that forms the top of the conventional H:Q ratio.
- Across 12 prospective studies, only eccentric knee flexor strength at 60°/s differed in athletes who later strained a hamstring — and the effect was small.

A small effect, one test only



12 studies, 508 hamstring strains in 2912 athletes; all other speeds and H:Q ratios showed no association. Green et al. (2018).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle from hip, knee and ankle landmarks in the side view. Educational, not diagnostic.

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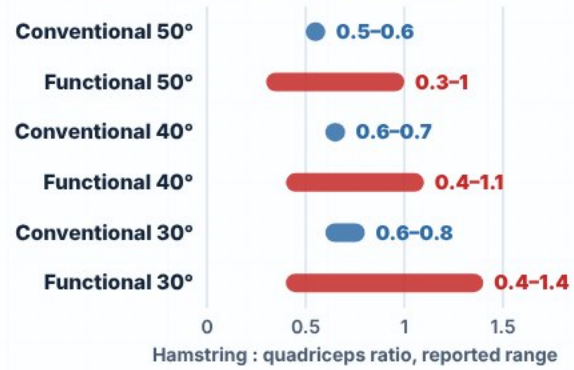
B · LEG EXTENSION, SIDE



Near extension, braking matters

- Leg extension with the knee almost straight (≈**11°** flexion): the quadriceps drive the shank, the action the hamstrings must brake eccentrically in late swing.
- The functional ratio (eccentric hamstring ÷ concentric quadriceps) approached 1:1 in fast extension and rose further as the knee neared extension.

The "60%" rule is only half the story



Knee angle of the torque comparison (50° includes peak moment); 30 and 240°/s. Aagaard et al. (1998).

Myth: "Below 0.6 you will tear a hamstring." 0.5–0.6 is only the conventional ratio at one angle.

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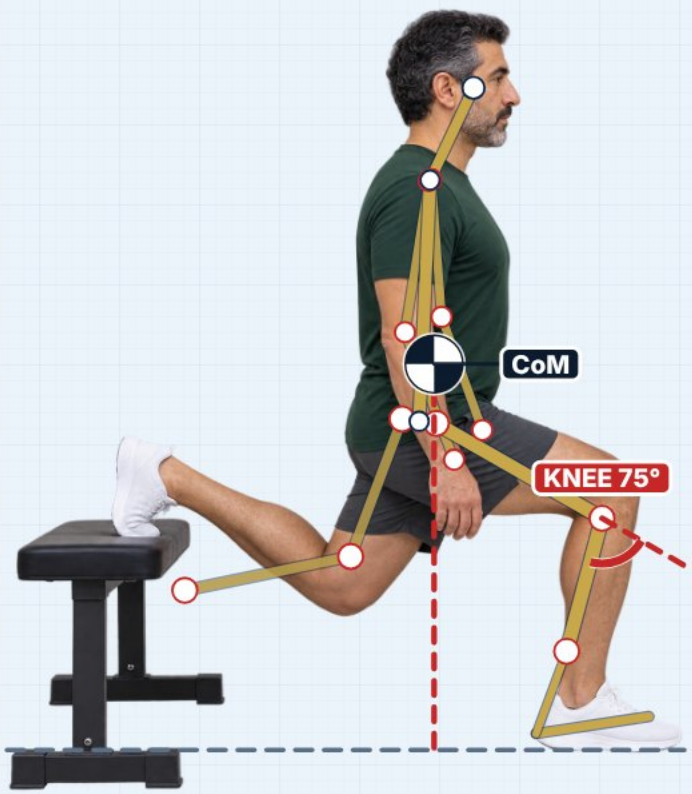
BIOMECHANICS IS A FORCE-GOVERNED DECISION SYSTEM – NOT A POSTURE MODEL.

INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

THIGH MUSCLE IMBALANCE: WHAT THE HAMSTRING-TO-QUADRICEPS RATIO MEANS

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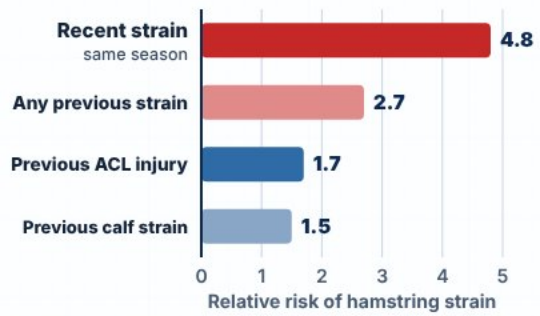
C · SPLIT SQUAT, SIDE



History outweighs a ratio

- Split squat with the front knee flexed ≈**75°**: quadriceps and hamstrings co-work through range, a closed-chain counterpart to the isolated machine tests.
- In 71 324 athletes, previous injury and older age predicted hamstring strain; none of 13 strength variables did.

What does predict a strain



78 studies, 8319 hamstring strains; all P ≤ 0.002. Green et al. (2020).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Front-knee angle from hip, knee and ankle landmarks in the side view. Educational, not diagnostic.

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A · Seated leg curl
Knee ≈108°

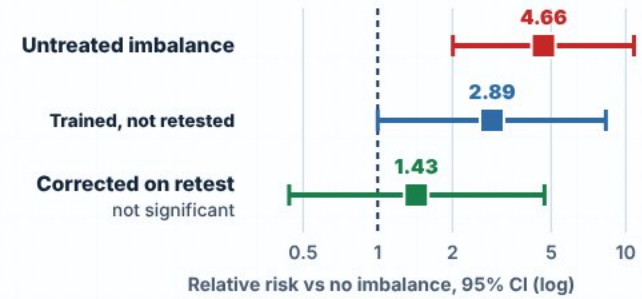


B · Leg extension
Knee ≈11°



C · Split squat
Knee ≈75°

Correct it, then confirm it



462 professional footballers with full follow-up, 35 hamstring injuries. Croisier et al. (2008).

Decision pathway

1. **PROFILE**
   Test conventional and functional ratios at more than one speed, alongside injury history and age.
2. **TRAIN**
   Target a clear deficit with eccentric hamstring and quadriceps work.
3. **RETEST**
   Confirm the imbalance is corrected; never clear or bar an athlete on one ratio.

NOT RECOMMENDED

Using a single H:Q cut-off to predict injury or to decide return to play.

SEEK ASSESSMENT IF

A pop with sudden strength loss, a palpable gap, marked bruising, inability to straighten the knee, or numbness with weakness.

REFERENCES (APA 7)

Aagaard, P., Simonsen, E. B., Magnusson, S. P., Larsson, B., & Dyhre-Poulsen, P. (1998). A new concept for isokinetic hamstring:quadriceps muscle strength ratio. *American Journal of Sports Medicine, 26*(2), 231–237. https://doi.org/10.1177/036354659802600212O1

Croisier, J.-L., Ganteaume, S., Binet, J., Genty, M., & Ferret, J.-M. (2008). Strength imbalances and prevention of hamstring injury in professional soccer players: A prospective study. *American Journal of Sports Medicine, 36*(8), 1469–1475. https://doi.org/10.1177/0363546508316764

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Green, B., Bourne, M. N., & Pizzari, T. (2018). Isokinetic strength assessment offers limited predictive validity for detecting risk of future hamstring strain in sport: A systematic review and meta-analysis. *British Journal of Sports Medicine, 52*(5), 329.

Green, B., Bourne, M. N., van Dyk, N., & Pizzari, T. (2020). Recalibrating the risk of hamstring strain injury (HSI): A 2020 systematic review and meta-analysis of risk factors for index and recurrent hamstring strain injury in sport. *British Journal of Sports Medicine, 54*(18), 1081–1088. https://doi.org/10.1136/bjsports-2019-100983

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

Analysis: MMSx Authority Applied Biomechanics Lab · Dr. Neeraj Mehta, PhD · Educational content, not a diagnosis.

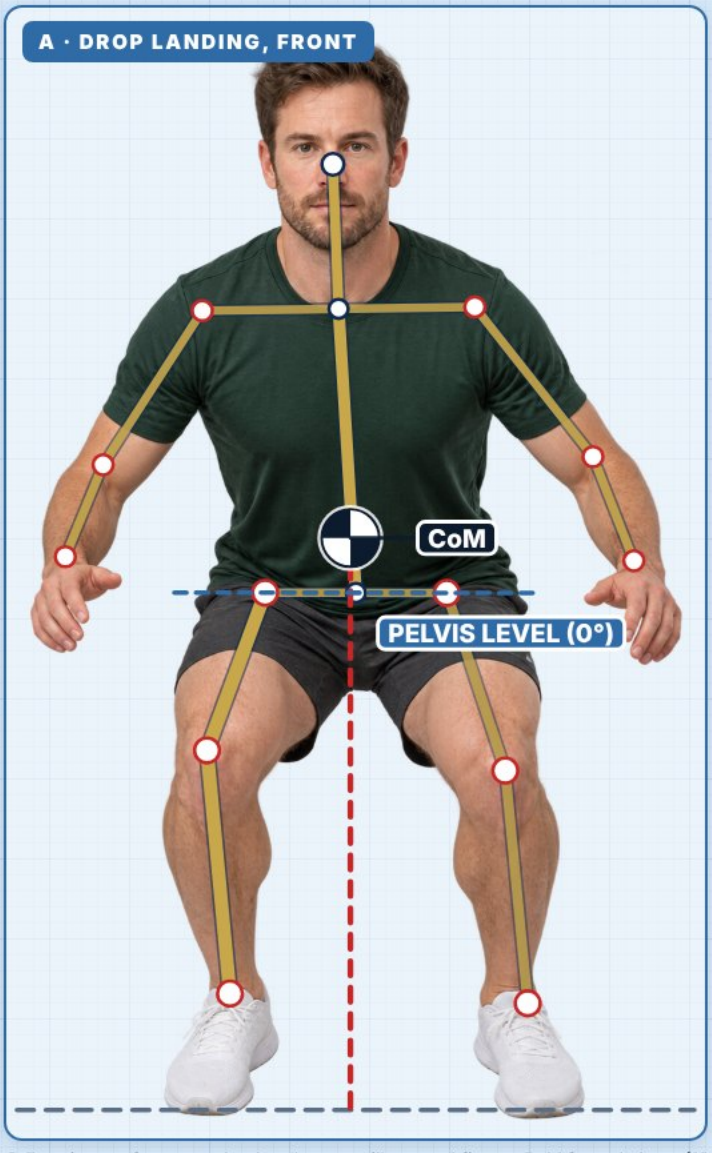
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HAMSTRING-TO-QUADRICEPS RATIO AND ACL RISK: WHAT IS PROVEN

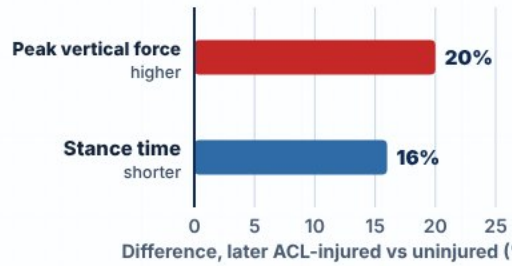
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Watch the knees, not only the ratio

- Two-footed landing from a low box, knees bent and tracking over the toes, pelvis level (**0°**): the front view is where inward knee collapse shows.
- In 205 screened female athletes, the 9 who later ruptured the ACL landed with 8° more knee abduction and a 2.5 times greater knee abduction moment.

A stiffer, harder landing



Prospective 3-D screening, drop vertical jump; 9 ACL ruptures vs 196 uninjured. Hewett et al. (2005).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Pelvis line from the two hip landmarks in the front view; knee angles not quoted in this view. Educational, not diagnostic.

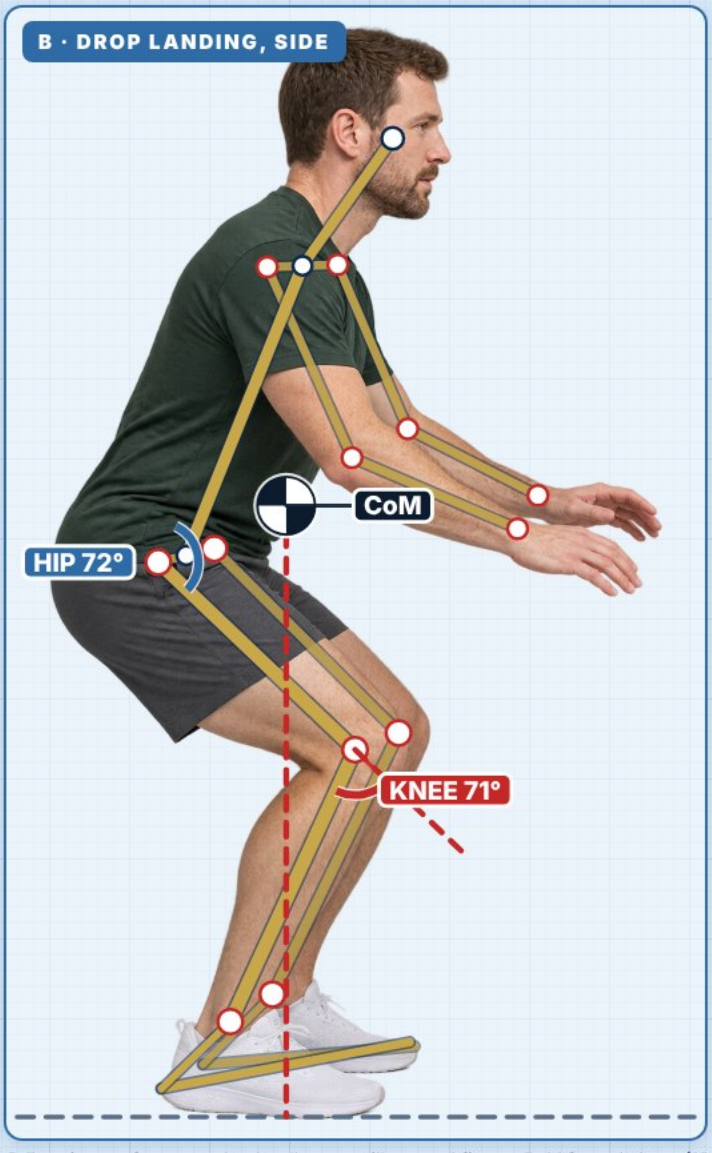
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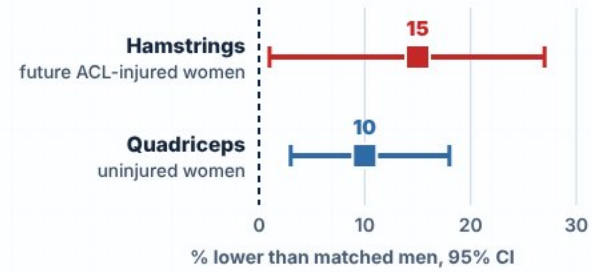
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The hamstrings brake the shin

- Same landing from the side, hip flexed **72°** and knee **71°**, trunk leaning forward: flexed hips and knees let the hamstrings resist forward shear of the tibia.
- Women who later injured the ACL had 15% lower hamstring strength than matched men. This supports, but does not prove, the H:Q hypothesis.

A hamstring deficit, small sample



Isokinetic concentric strength at 300°/s; 22 women who later injured the ACL. Myer et al. (2009).

Key point: a low H:Q ratio is a plausible risk factor for a first ACL injury, not a proven stand-alone predictor.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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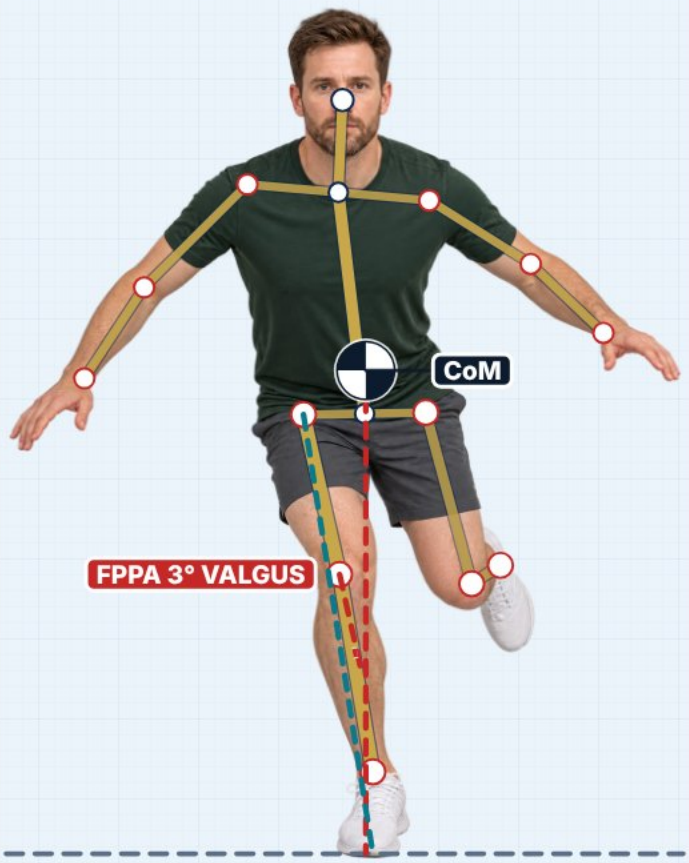
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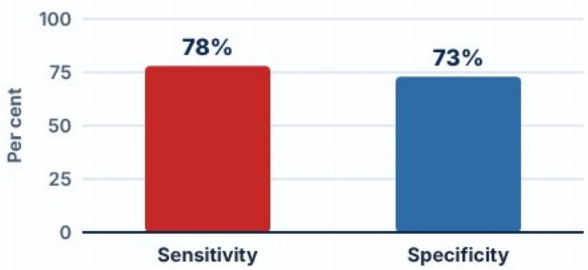
C · SINGLE-LEG LANDING, FRONT



Knee over foot on one leg

- Landing on the right leg with arms out for balance, knee within **3°** of the hip–ankle line: the aligned position that landing programmes coach.
- Knee abduction moment predicted later ACL injury with 78% sensitivity and 73% specificity — useful, but it still misclassifies some athletes.

How well the moment predicts



Knee abduction moment at landing as predictor of ACL injury; 205 female athletes. Hewett et al. (2005).

Myth: "An H:Q ratio above 0.6 protects the ACL." Landing mechanics were the measured first-injury signal.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Frontal-plane knee angle from hip, knee and ankle landmarks in the front view. Educational, not diagnostic.

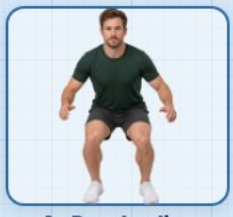
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A · Drop landing
Front view



B · Drop landing
Hip 72°, knee 71°



C · Single-leg landing
Knee within 3°

Prevention programmes halve ACL injuries



Summary of 8 meta-analyses of ACL injury prevention training; I^2 = 15%. Webster and Hewett (2018).

Decision pathway

1. **TRAIN**
   Use multi-component programmes: landing, strength and balance, not one ratio.
2. **COACH**
   Cue soft landings with the knee over the foot; limit inward knee collapse.
3. **RETURN**
   After reconstruction, check H:Q ratio and all discharge criteria; missing any was linked to 4 times the graft rupture risk.

NOT RECOMMENDED

Using the H:Q ratio alone to screen healthy athletes or to clear return to sport.

SEEK ASSESSMENT IF

A pop at injury, rapid knee swelling, the knee giving way or locking, or being unable to continue playing.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Jr., Colosimo, A. J., McLean, S. G., van den Bogert, A. J., Paterno, M. V., & Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. *American Journal of Sports Medicine, 33*(4), 492–501. https://doi.org/10.1177/0363546504269591

Kyritsis, P., Bahr, R., Landreau, P., Miladi, R., & Witvrouw, E. (2016). Likelihood of ACL graft rupture: Not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *British Journal of Sports Medicine, 50*(15), 946. https://doi.org/10.1136/bjsports-2015-095908

Myer, G. D., Ford, K. R., Barber Foss, K. D., Liu, C., Nick, T. G., & Hewett, T. E. (2009). The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. *Clinical Journal of Sport Medicine, 19*(1), 3–8. https://doi.org/10.1097/JSM.0b013e318190bddb

Webster, K. E., & Hewett, T. E. (2018). Meta-analysis of meta-analyses of anterior cruciate ligament injury reduction training programs. *Journal of Orthopaedic Research, 36*, 2696–2708. https://doi.org/10.1002/jor.24043

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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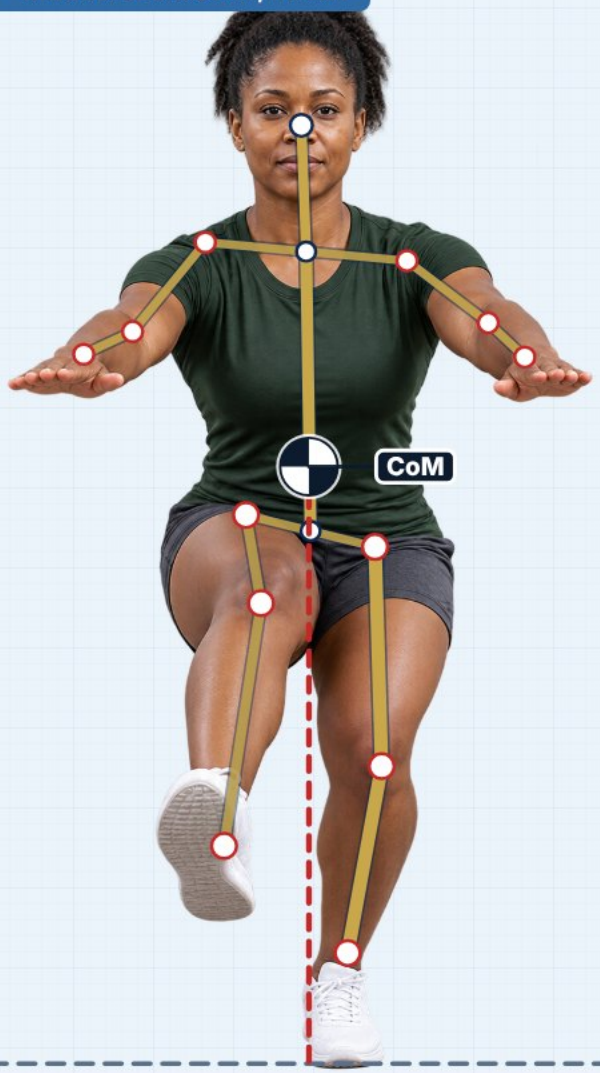
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SINGLE-LEG STRENGTH DIFFERENCES: WHEN THIGH ASYMMETRY MATTERS

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A · SINGLE-LEG SQUAT, FRONT



One leg at a time shows the gap

- Single-leg squat with the other leg held forward and arms reaching ahead: each thigh must control the body alone, so a side-to-side deficit cannot be hidden by the stronger leg.
- After ACL reconstruction, each 1 percentage-point gain in quadriceps strength symmetry was linked to 3% fewer knee reinjuries.

Passing the tests mattered



106 pivoting-sport athletes after ACL reconstruction, Delaware–Oslo cohort. Grindem et al. (2016).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Front view: landmarks shown for reference; no angles quoted for this pose. Educational, not diagnostic.

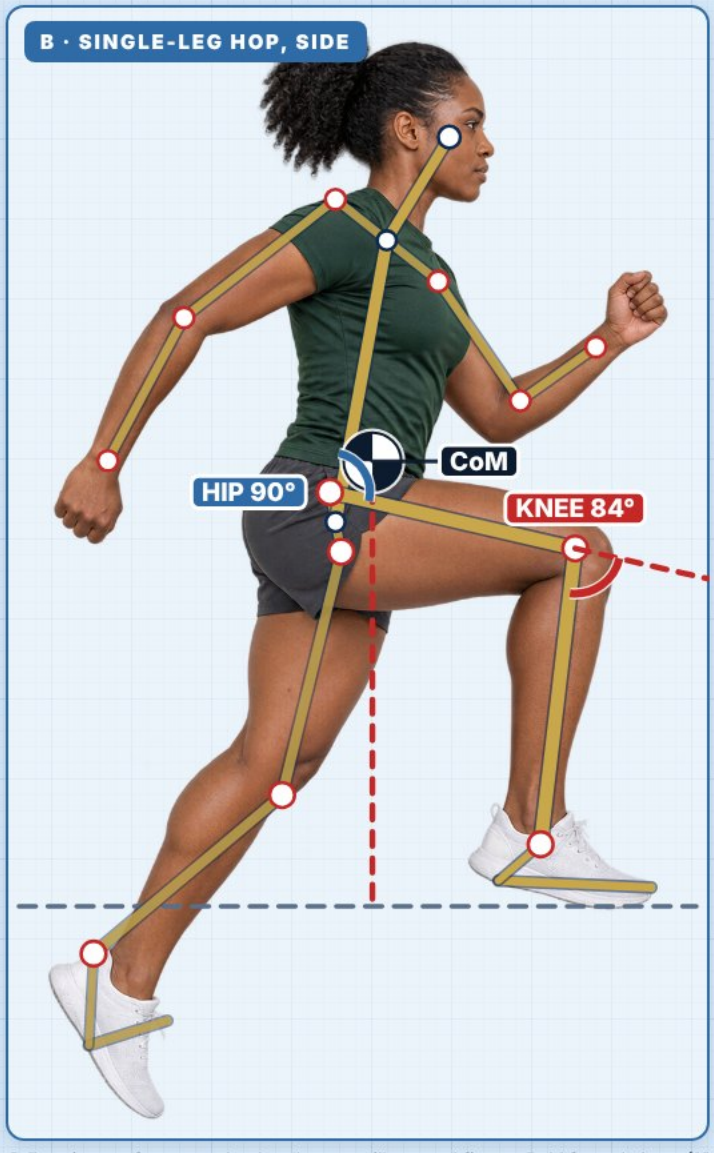
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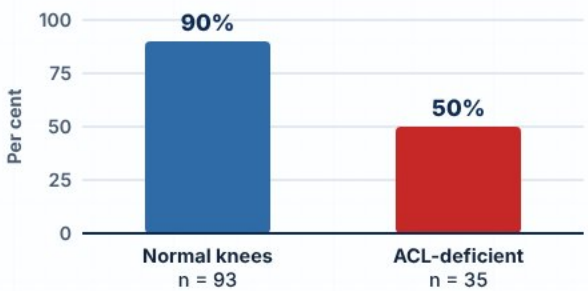
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The hop test and its cut-off

- Mid-air in a single-leg forward hop, free leg driven forward (hip ≈**90°**, knee ≈**84°**): the hopping leg alone must propel the body and then absorb the landing.
- The 85% symmetry cut-off came from healthy people, yet half of ACL-deficient knees hopped "normally" despite giving way in sport.

One hop test can miss a problem



Normal: more than 90% reached ≥85% symmetry (hop for distance, timed hop). ACL-deficient: share testing normal. Barber et al. (1990).

Key point: combine strength and several hop tests; a single test lacks sensitivity.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles of the free (forward) leg from pose landmarks in the side view; airborne poses are approximate. Educational, not diagnostic.

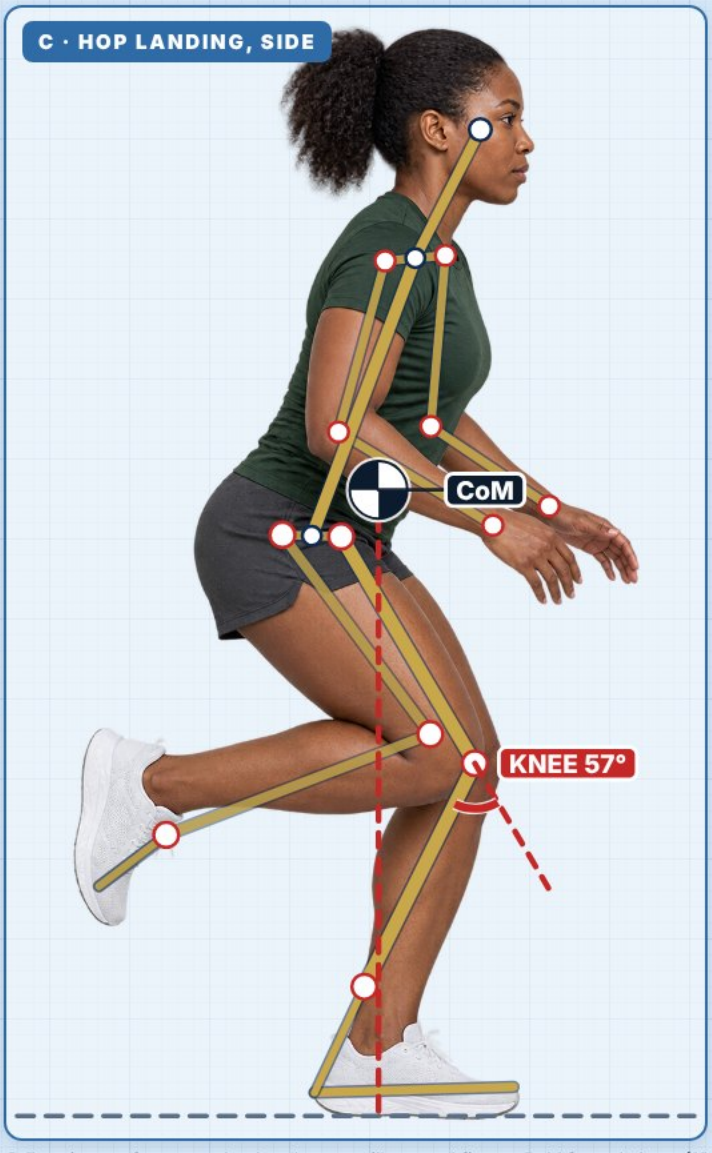
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Symmetry can flatter the knee

- Landing a single-leg hop, knee flexed ≈**57°** to absorb the impact, trunk leaning forward and the other leg trailing behind.
- After surgery the uninjured leg also weakens, so a "good" limb symmetry index can hide loss in both legs. Pre-injury values detected later re-tears better.

Pre-injury values detect more



70 athletes tested before and 6 months after ACL reconstruction; statistic labelled as sensitivity from the paper summary. Wellsandt et al. (2017).

Myth: "Once both legs hop the same distance, the knee is ready." Symmetry can come from the good leg getting weaker.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Landing-knee angle from hip, knee and ankle landmarks in the side view. Educational, not diagnostic.

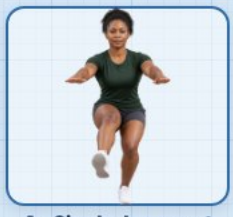
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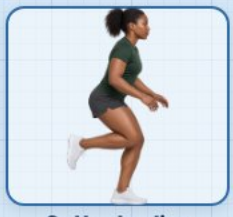
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A · Single-leg squat
Each leg alone

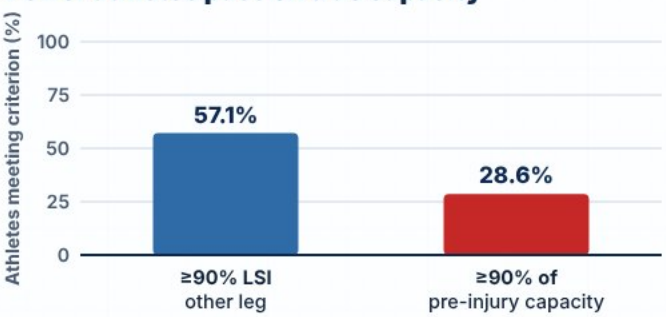


B · Single-leg hop
Distance test



C · Hop landing
Knee ≈57°

Fewer athletes pass on true capacity



Quadriceps strength plus 4 single-leg hop tests, 6 months after ACL reconstruction; n = 70. Wellsandt et al. (2017).

Decision pathway

1. **BATTERY**
   Test quadriceps strength and several hops, each at least 90%.
2. **COMPARE**
   Where possible, compare the injured leg with pre-injury values, not only the other leg.
3. **TIME**
   Delay pivoting sport to at least 9 months after ACL reconstruction.

NOT RECOMMENDED

Clearing an athlete on a single hop test, or on a date alone.

SEEK ASSESSMENT IF

New swelling after hopping or landing, the knee giving way or locking, or pain that rises from session to session.

REFERENCES (APA 7)

Barber, S. D., Noyes, F. R., Mangine, R. E., McCloskey, J. W., & Hartman, W. (1990). Quantitative assessment of functional limitations in normal and anterior cruciate ligament-deficient knees. *Clinical Orthopaedics and Related Research, 255*, 204–214. https://doi.org/10.1097/00003086-199006000-00028

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Grindem, H., Snyder-Mackler, L., Moksnes, H., Engebretsen, L., & Risberg, M. A. (2016). Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: The Delaware-Oslo ACL cohort study. *British Journal of Sports Medicine, 50*(13), 804.

Wellsandt, E., Failla, M. J., & Snyder-Mackler, L. (2017). Limb symmetry indexes can overestimate knee function after anterior cruciate ligament injury. *Journal of Orthopaedic & Sports Physical Therapy, 47*(5), 334–338. https://doi.org/10.2519/jospt.2017.7285

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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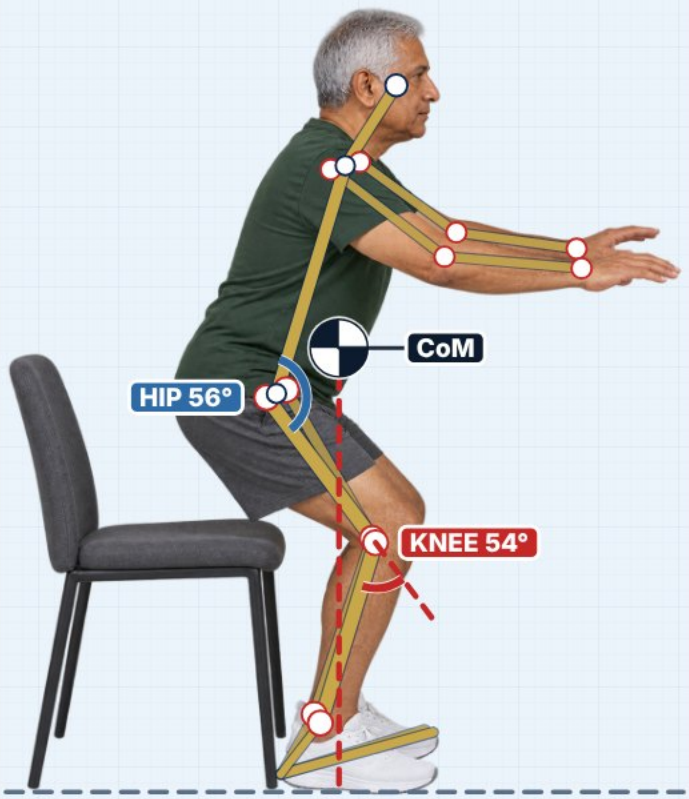
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THIGH MUSCLE LOSS WITH AGE: SARCOPENIA, STRENGTH AND FALLS

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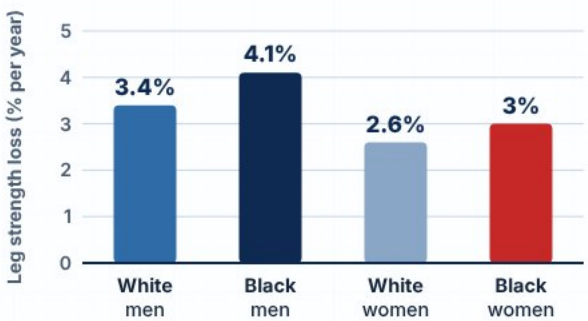
A · SIT TO STAND, SIDE



Rising from a chair needs force

- Halfway up from a chair without using the hands, hip flexed **56°** and knee **54°**, arms reaching forward: the quadriceps and hip extensors lift the body against gravity.
- Over three years, older adults lost leg strength about three times faster than leg lean mass (about 1% per year).

Strength fades faster than size



1880 well-functioning older adults, Health ABC Study, three-year follow-up. Goodpaster et al. (2006).

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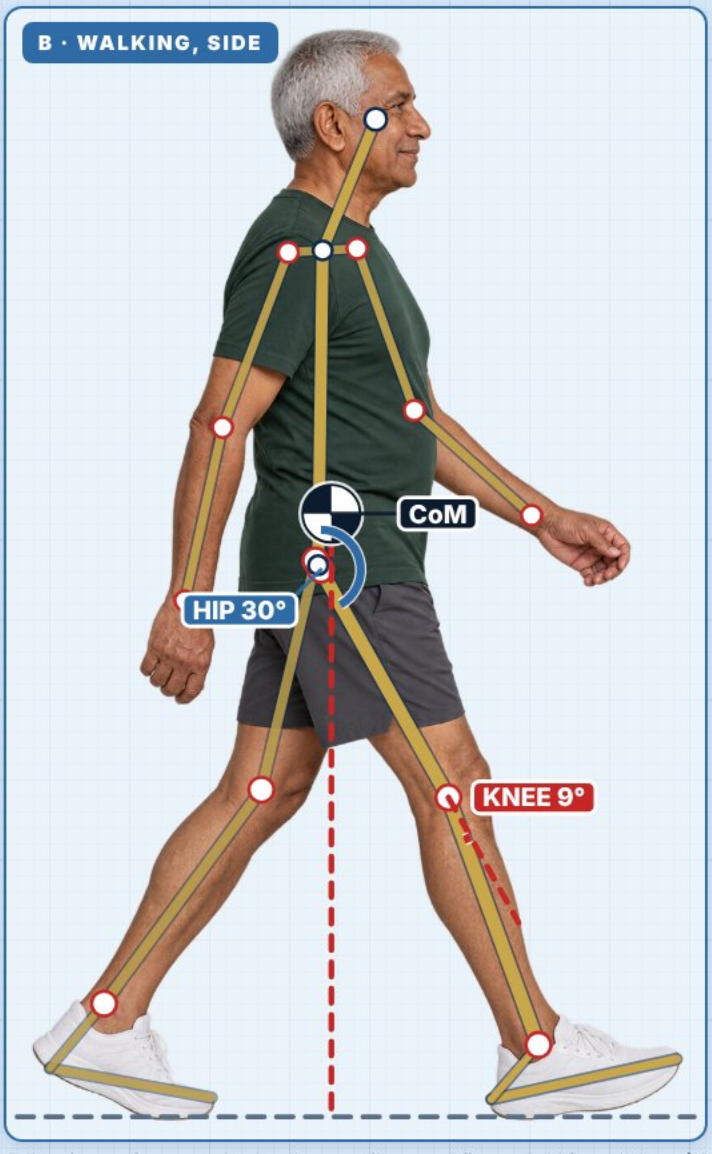
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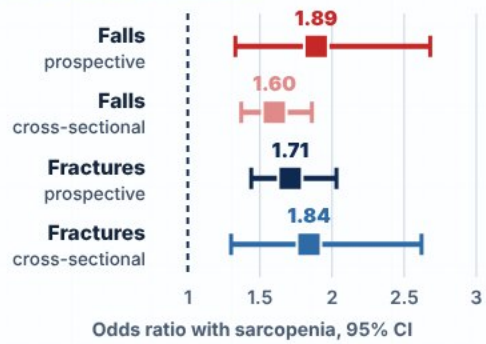
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Walking is a performance test

- Walking upright at a comfortable pace, front hip flexed ≈**30°** as the heel reaches forward: gait speed of 0.8 m/s or less marks low physical performance in EWGSOP2.
- Across 33 studies, sarcopenia was associated with higher odds of falls and fractures. These are associations, so strength is one of several fall-risk factors.

Sarcopenia travels with falls



33 studies, 45 926 older adults. Yeung et al. (2019); gait cut-off Cruz-Jentoft et al. (2019).

Key point: EWGSOP2 puts low strength first; muscle quantity confirms, and slow walking grades severity.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip angle of the forward leg from pose landmarks in the side view. Educational, not diagnostic.

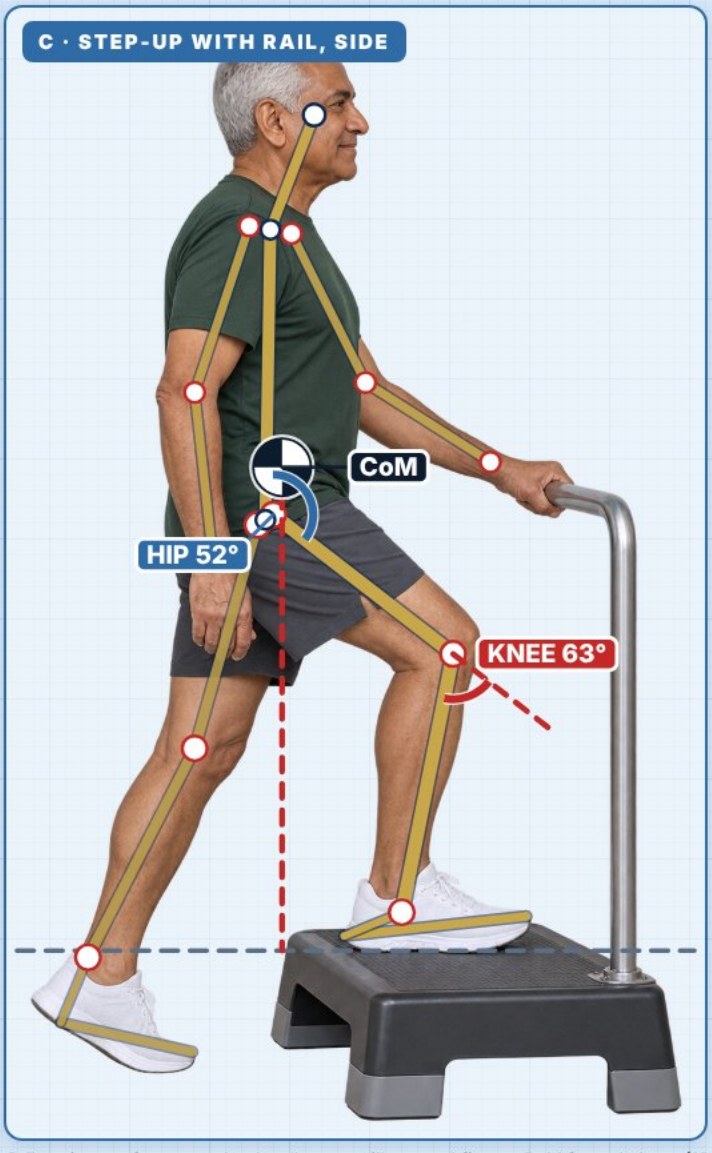
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BIOMECHANICS IS A FORCE-GOVERNED DECISION SYSTEM – NOT A POSTURE MODEL.

INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

THIGH MUSCLE LOSS WITH AGE: SARCOPENIA, STRENGTH AND FALLS

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Step-ups train the same muscles

- Stepping up onto a low step, one hand on a rail for safety, lead hip flexed **52°** and knee **63°**: a progressive, everyday way to load the thigh.
- Progressive resistance training had a large effect on strength and a moderate to large effect on chair rising; the gain in overall physical ability was small.

Strength is trainable in later life



Cochrane review, 121 trials, 6700 older participants. Liu and Latham (2009).

Myth: "Muscle loss with age is inevitable." Resistance training improved strength and chair rising.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Lead-leg hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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A · Sit to stand
Knee 54°

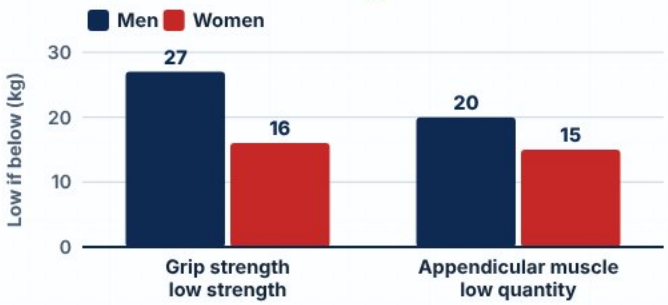


B · Walking
Gait speed test



C · Step-up
Knee 63°

EWGSOP2 thresholds in kilograms



Low strength also: five chair rises >15 s; low performance: gait ≤0.8 m/s.
Cruz-Jentoft et al. (2019).

Decision pathway

1. **SCREEN**
   Test strength first with grip strength or five chair rises.
2. **CONFIRM**
   Confirm with muscle quantity; grade severity with gait speed or similar tests.
3. **TRAIN**
   Prescribe progressive resistance training, with chair rising and step-ups.

NOT RECOMMENDED

Accepting thigh weakness as "just age", or relying on muscle size alone.

SEEK ASSESSMENT IF

Rapid unexplained weakness or weight loss, new or repeated falls, inability to rise without the arms, or weakness with pain, dark urine or fever.

REFERENCES (APA 7)

Cruz-Jentoft, A. J., Bahat, G., Bauer, J., Boirie, Y., Bruyère, O., Cederholm, T., Cooper, C., Landi, F., Rolland, Y., Sayer, A. A., Schneider, S. M., Sieber, C. C., Topinkova, E., Vandewoude, M., Visser, M., Zamboni, M., Writing Group for the European Working Group on Sarcopenia in Older People 2 (EWGSOP2), & the Extended Group for EWGSOP2. (2019). Sarcopenia: Revised European consensus on definition and diagnosis. *Age and Ageing, 48*(1), 16–31. https://doi.org/10.1093/ageing/afy169

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Goodpaster, B. H., Park, S. W., Harris, T. B., Kritchevsky, S. B., Nevitt, M., Schwartz, A. V., Simonsick, E. M., Tylavsky, F. A., Visser, M., & Newman, A. B. (2006). The loss of skeletal muscle strength, mass, and quality in older adults: The Health, Aging and Body Composition Study. *Journals of Gerontology: Series A, Biological Sciences and Medical Sciences, 61*(10), 1059–1064. https://doi.org/10.1093/gerona/61.10.1059

Liu, C.-J., & Latham, N. K. (2009). Progressive resistance strength training for improving physical function in older adults. *Cochrane Database of Systematic Reviews, 2009*(3), CD002759. https://doi.org/10.1002/14651858.CD002759.pub2

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

Yeung, S. S. Y., Reijnierse, E. M., Pham, V. K., Trappenburg, M. C., Lim, W. K., Meskers, C. G. M., & Maier, A. B. (2019). Sarcopenia and its association with falls and fractures in older adults: A systematic review and meta-analysis. *Journal of Cachexia, Sarcopenia and Muscle, 10*(3), 485–500. https://doi.org/10.1002/jcsm.12411

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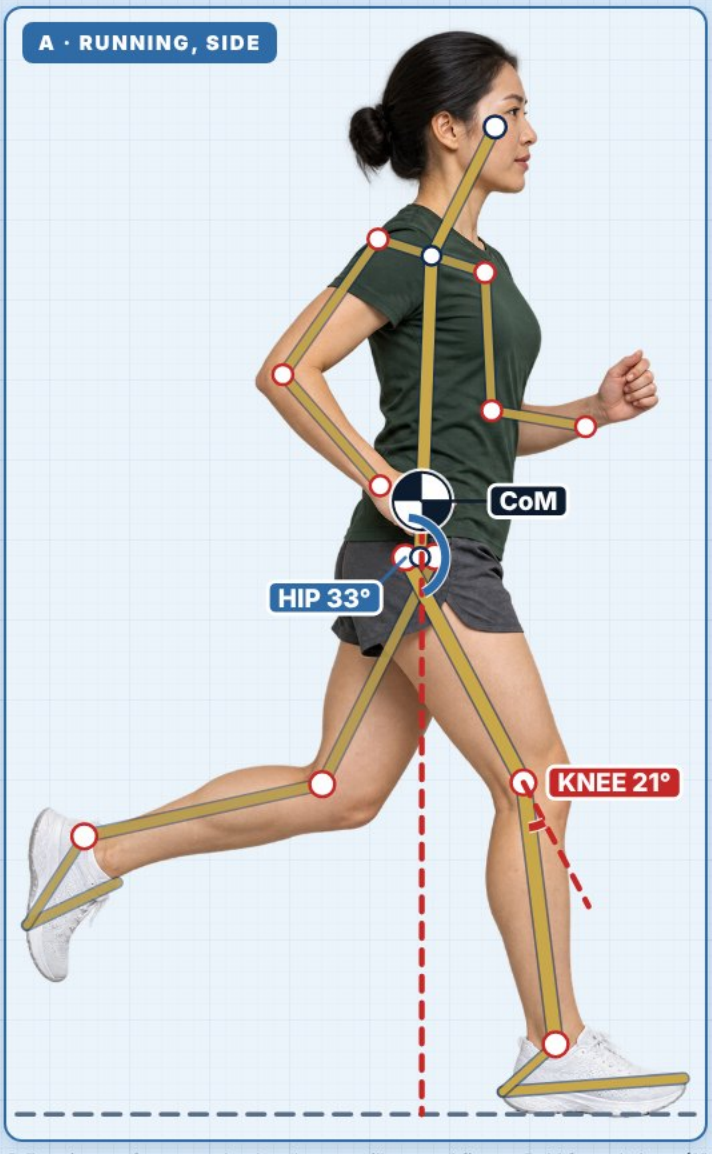
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THIGH PAIN IN RUNNERS: STRESS REACTION, STRAIN OR OVERLOAD?

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Every stride is a bone load

- Running with the front foot landing slightly ahead of the body, knee flexed ≈**21°** and hip ≈**33°**: thousands of such impacts per run load the femur and thigh muscles.
- Previous injury, and in men more than 64 km per week, were the strongest evidenced risk factors for running injury.

Where running injuries occur



Systematic review of prospective cohorts in long-distance runners; ranges reflect differing definitions. van Gent et al. (2007).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Front-leg hip and knee angles from pose landmarks in the side view; running poses are approximate. Educational, not diagnostic.

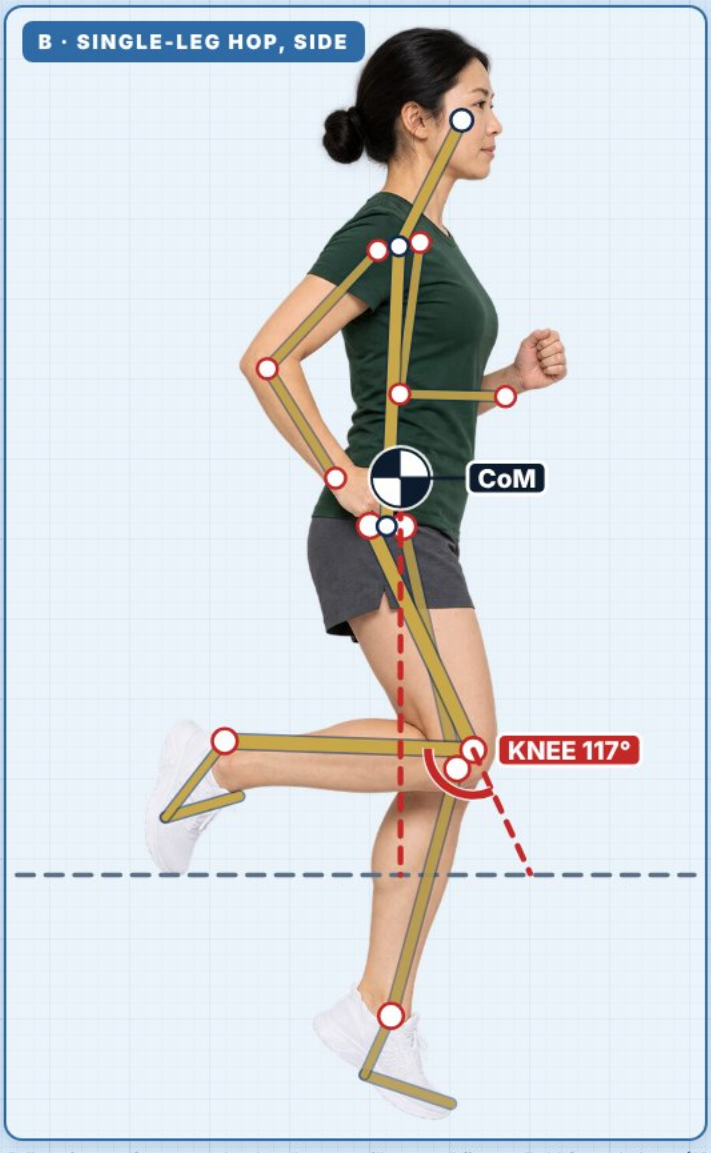
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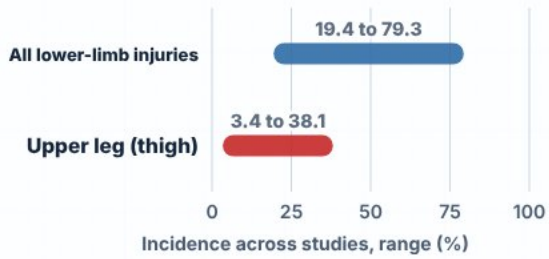
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Hopping separates bone from muscle

- Hopping on one leg on the spot, the free knee flexed ≈**117°** behind: each landing sends impact through one femur, so focal pain on hopping raises suspicion of bone stress.
- Sudden pain during fast running suggests strain; a gradual ache that settles with less load suggests overload.

Thigh trouble is common in runners



Incidence of lower-extremity running injuries, and of upper-leg injuries, across prospective studies. van Gent et al. (2007).

Key point: pain on hopping is a reason to stop and be assessed, not to run through it.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Free-leg knee angle from pose landmarks in the side view; airborne poses are approximate. Educational, not diagnostic.

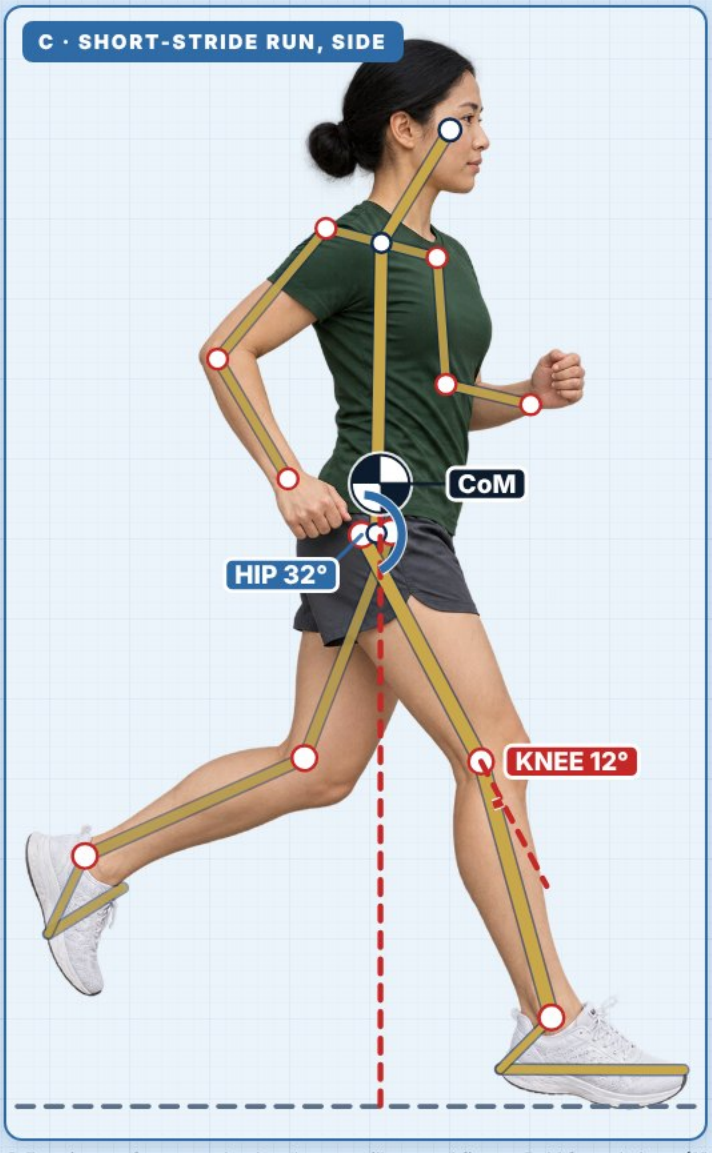
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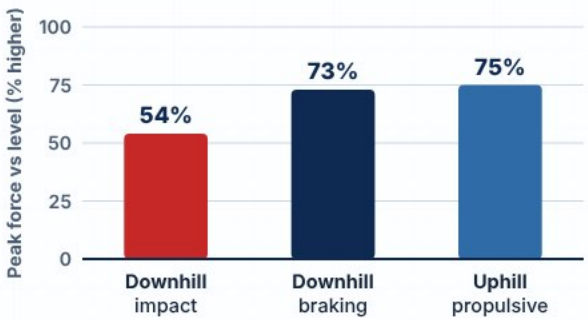
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Slopes change the load

- Running tall with a short stride, front knee ≈**12°** as the foot meets the ground; on a downhill the same stride must also brake the body, loading the quadriceps eccentrically.
- On a 9° downhill, impact and braking force peaks rose by 54% and 73%; reducing downhill running during recovery is a sensible load change.

Downhill raises impact and braking



10 runners at 3 m/s on a force treadmill, ±9° slopes; uphill had no impact peak. Gottschall and Kram (2005).

Myth: "No swelling or bruise, so it is just a tight muscle." Bone stress often looks like nothing outside.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Front-leg knee angle from pose landmarks in the side view; no slope is drawn in the image. Educational, not diagnostic.

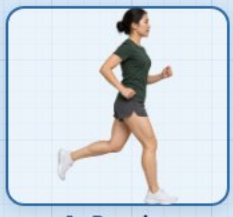
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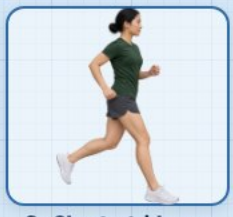
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A · Running
Knee ≈21°

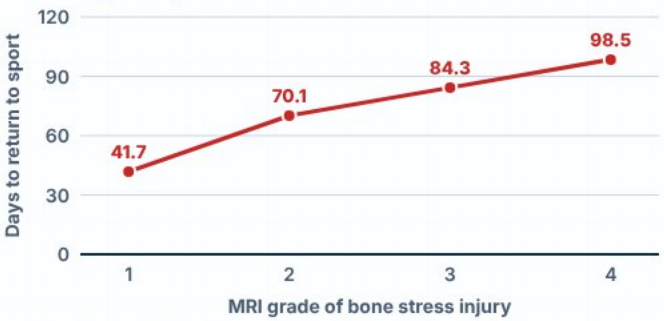


B · Single-leg hop
Provocation test



C · Short-stride run
Lower braking

Earlier grade, faster return



16 studies, 560 bone stress injuries; grade 1 mean 41.7 days (95% CI 30.6–52.9), grade 4 98.5 (85.5–112.6). Hoenig et al. (2022).

Decision pathway

1. **SORT**
   Sudden onset in sprinting: strain. Gradual focal pain with impact: suspect bone stress.
2. **IMAGE**
   Refer focal bone pain for MRI; the grade guides time out.
3. **LOAD**
   Cut weekly distance and downhill running, then rebuild gradually.

NOT RECOMMENDED

Running through deep, worsening thigh pain or pain on hopping.

SEEK ASSESSMENT IF

Deep thigh or groin pain that worsens with each run, pain at night or rest, a limp, or pain on hopping: stop running and seek prompt assessment.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Gottschall, J. S., & Kram, R. (2005). Ground reaction forces during downhill and uphill running. *Journal of Biomechanics, 38*(3), 445–452. https://doi.org/10.1016/j.jbiomech.2004.04.023

Hoenig, T., Tenforde, A. S., Strahl, A., Rolvien, T., & Hollander, K. (2022). Does magnetic resonance imaging grading correlate with return to sports after bone stress injuries? A systematic review and meta-analysis. *American Journal of Sports Medicine, 50*(3), 834–844. https://doi.org/10.1177/0363546521993807

van Gent, R., Siem, D., van Middelkoop, M., van Os, A. G., Bierma-Zeinstra, S. M., & Koes, B. W. (2007). Incidence and determinants of lower extremity running injuries in long distance runners: A systematic review. *British Journal of Sports Medicine, 41*(8), 469–480. https://doi.org/10.1136/bjsm.2006.033548

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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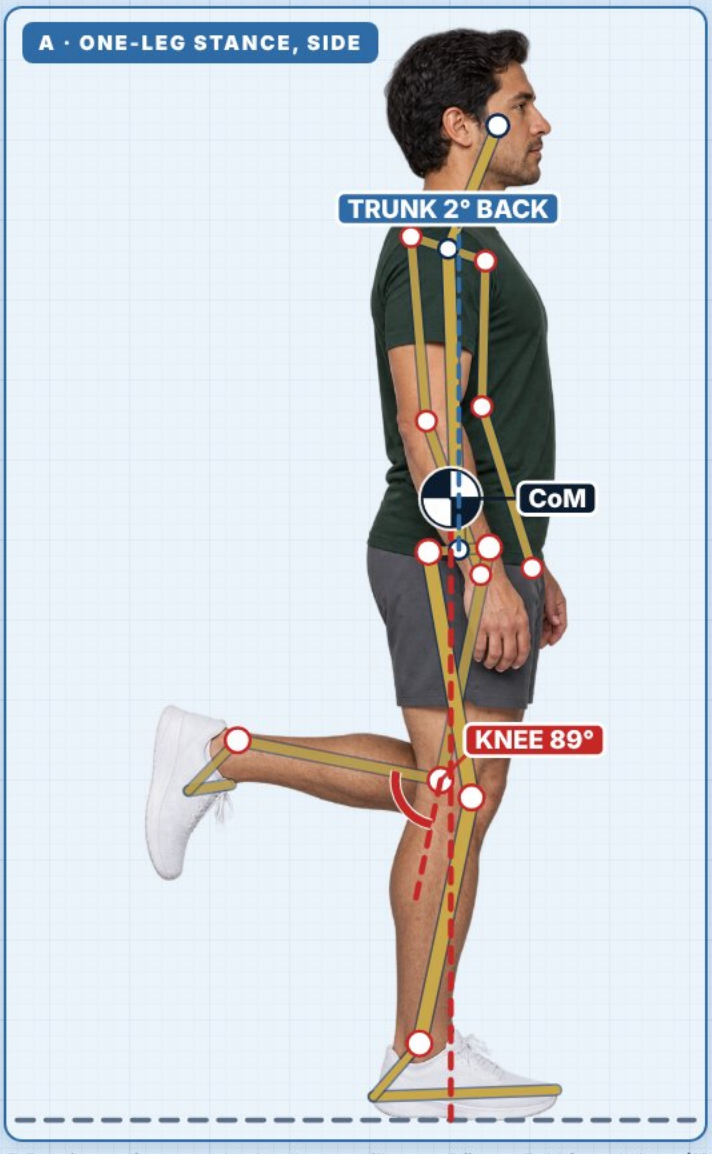
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FEMORAL STRESS FRACTURE: DEEP THIGH PAIN THAT SHOULD NOT BE IGNORED

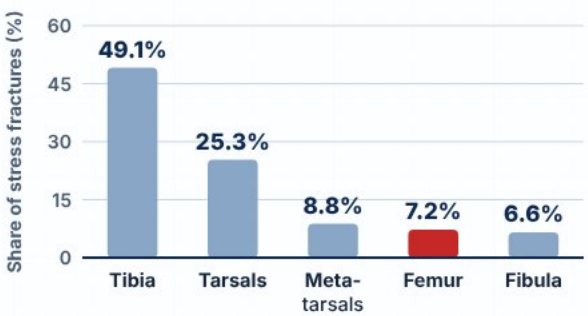
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Standing on one leg loads one femur

- Upright on one leg, trunk within **2°** of vertical, the other knee bent **≈89°** behind: all body weight passes through one femur, so pain here is a warning sign.
- The femur was a minority site in 320 athletes, but made up 20.6% of stress fractures in a prospective collegiate cohort, so it may be under-recognised.

Where stress fractures occur



320 athletes, bone-scan-positive; pelvis, sesamoids and spine each under 2%. Matheson et al. (1987); Johnson et al. (1994).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line and lifted-leg knee angle from pose landmarks in the side view. Educational, not diagnostic.

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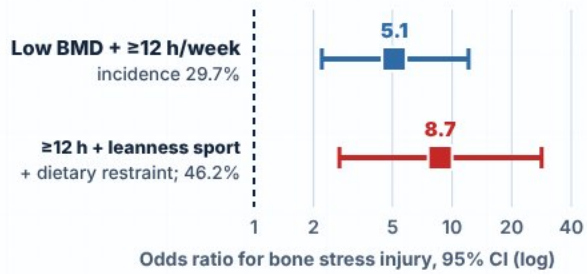
B · ENDURANCE RUN, SIDE



Volume and energy add up

- Long relaxed endurance stride, front hip flexed ≈**52°** and knee ≈**35°**: repeated over many kilometres, loading can outpace the bone's ability to remodel.
- In 259 exercising girls and women, bone stress injury rose from about 15–21% with one risk factor to 30–46% with combined factors.

Risk factors multiply



Prospective multisite study; 28 of 259 (10.8%) had a bone stress injury. Barrack et al. (2014).

Key point: energy intake, menstrual function and bone health belong in the assessment of any runner with deep thigh pain.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Front-leg hip and knee angles from pose landmarks in the side view; running poses are approximate. Educational, not diagnostic.

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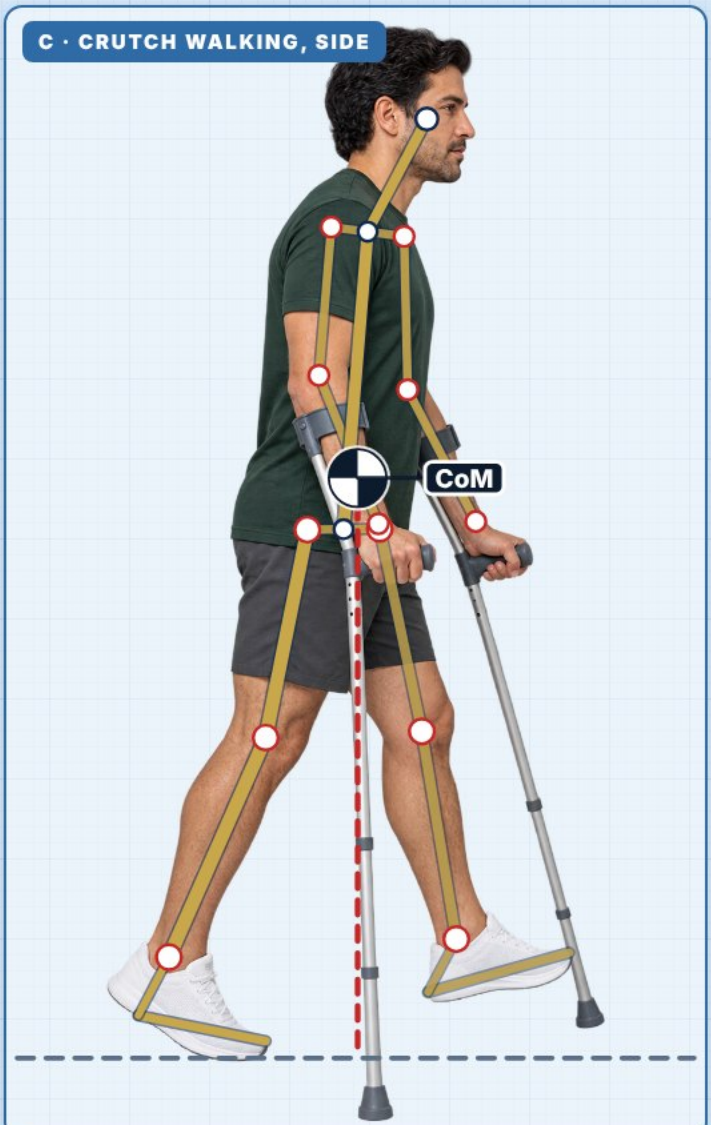
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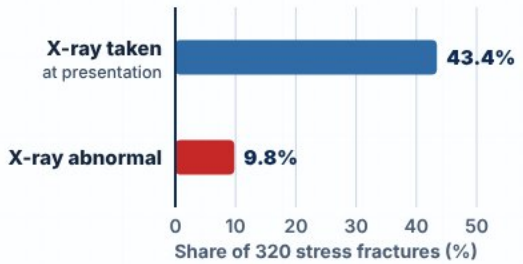
C · CRUTCH WALKING, SIDE



Protect it, then rebuild

- Walking with two elbow crutches, trunk upright and weight shared through the arms: protected weight-bearing is one option a specialist may choose for a femoral stress fracture.
- Diagnosis took 13.4 weeks on average, longer than the 12.8 weeks to recover, and few X-rays showed the fracture.

A normal X-ray does not exclude it



320 bone-scan-positive stress fractures in athletes. Matheson et al. (1987).

Myth: "My X-ray was normal, so it cannot be a fracture." Only 9.8% showed on X-ray; persistent deep pain needs MRI.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Crutch walking: landmarks shown for reference; no angles quoted. Educational, not diagnostic.

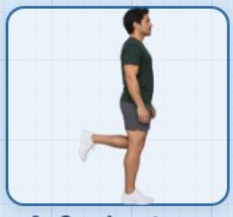
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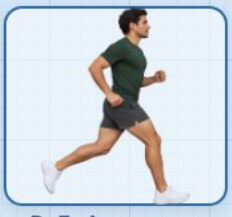
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A · One-leg stance
Provocation test

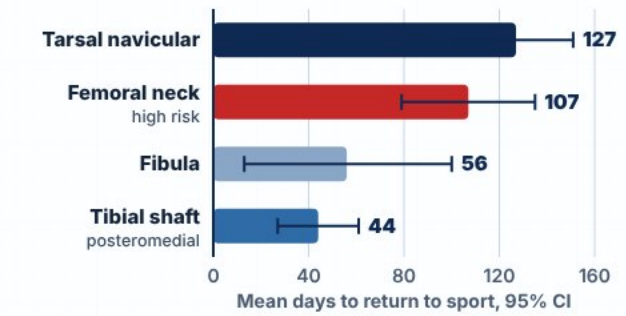


B · Endurance run
Hip ≈52°



C · Crutch walking
Protected loading

The femoral neck means months



76 studies, 2974 bone stress injuries; more than 90% returned to sport. Hoenig et al. (2023).

Decision pathway

1. **SUSPECT**
   Deep thigh, hip or groin pain that builds with running needs early assessment.
2. **IMAGE**
   Seek MRI when pain persists; a normal X-ray does not rule out a stress fracture.
3. **ADDRESS**
   Review training volume, energy intake, menstrual health and bone density.

NOT RECOMMENDED

Running through deep thigh pain, or relying on a normal X-ray.

SEEK ASSESSMENT IF

Deep groin, hip or thigh pain worse with each run, at night or at rest, a limp, or pain on hopping: stop running and seek same-day medical assessment.

REFERENCES (APA 7)

Barrack, M. T., Gibbs, J. C., De Souza, M. J., Williams, N. I., Nichols, J. F., Rauh, M. J., & Nattiv, A. (2014). Higher incidence of bone stress injuries with increasing female athlete triad-related risk factors: A prospective multisite study of exercising girls and women. *American Journal of Sports Medicine, 42*(4), 949–958. https://doi.org/10.1177/0363546513520295

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Hoenig, T., Eissele, J., Strahl, A., Popp, K. L., Stürznickel, J., Ackerman, K. E., Hollander, K., Warden, S. J., Frosch, K.-H., Tenforde, A. S., & Rolvien, T. (2023). Return to sport following low-risk and high-risk bone stress injuries: A systematic review and meta-analysis. *British Journal of Sports Medicine, 57*(7), 427–432. https://doi.org/10.1136/bjsports-2022-106328

Johnson, A. W., Weiss, C. B., & Wheeler, D. L. (1994). Stress fractures of the femoral shaft in athletes—more common than expected: A new clinical test. *American Journal of Sports Medicine, 22*(2), 248–256. https://doi.org/10.1177/036354659402200216

Matheson, G. O., Clement, D. B., McKenzie, D. C., Taunton, J. E., Lloyd-Smith, D. R., & MacIntyre, J. G. (1987). Stress fractures in athletes: A study of 320 cases. *American Journal of Sports Medicine, 15*(1), 46–58. https://doi.org/10.1177/036354658701500107

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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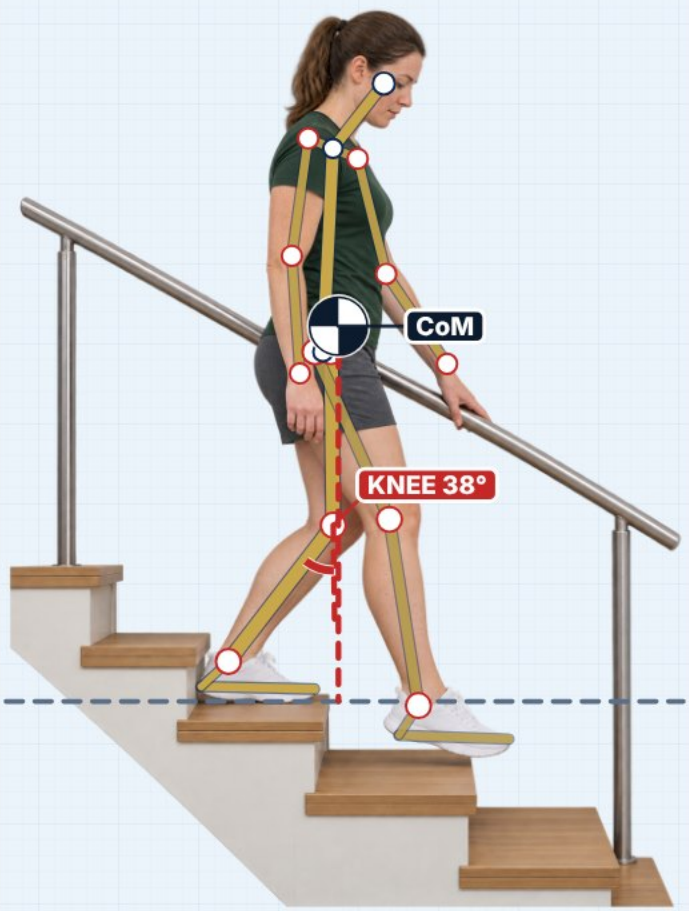
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THIGH PAIN AFTER A LONG RUN: SORENESS OR INJURY?

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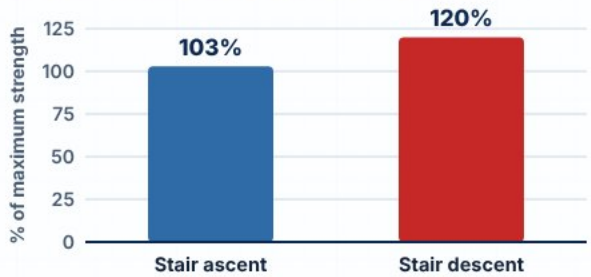
A · STAIR DESCENT, SIDE



Why stairs down hurt most

- Stepping down with a hand on the rail: the trailing knee, flexed ≈**38°**, lowers the body while the quadriceps lengthen under load — an eccentric task.
- Descending stairs needed a larger share of quadriceps strength than climbing, so sore thighs after a long or downhill run are felt most on the way down.

Descent asks more of the quadriceps



Required knee extensor moment as % of maximum isometric strength; 84 adults aged 60–88, so a mechanical illustration. Samuel et al. (2011).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trailing-knee angle from hip, knee and ankle landmarks in the side view. Educational, not diagnostic.

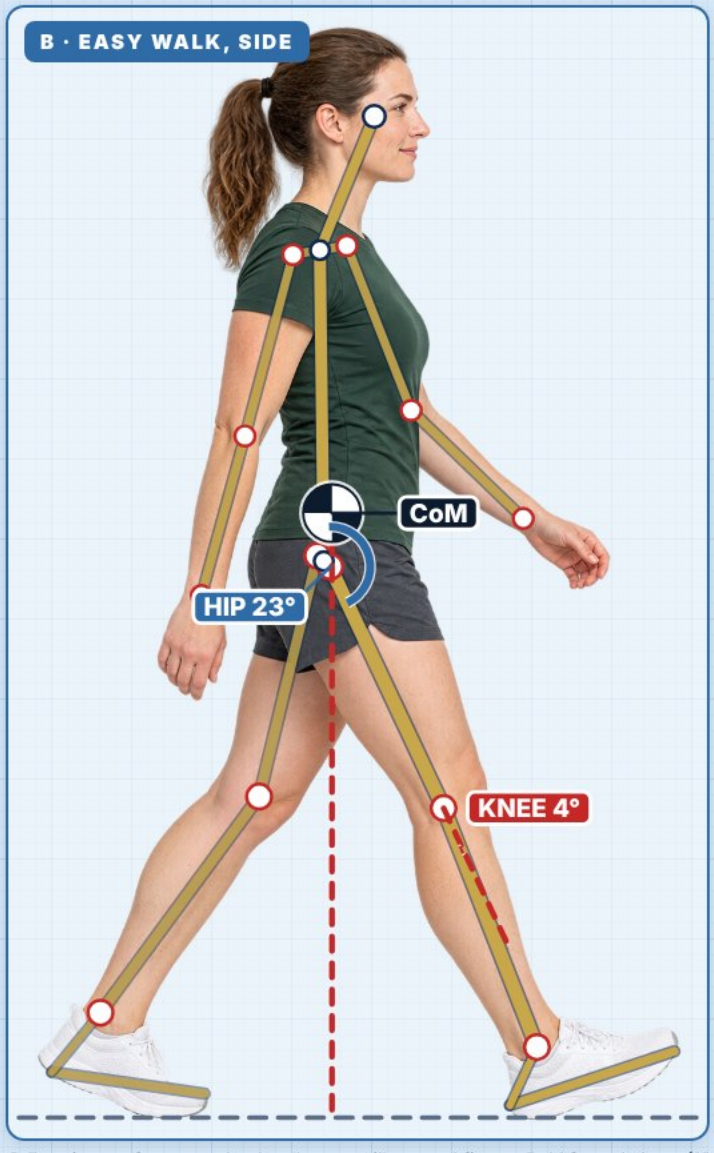
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INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

THIGH PAIN AFTER A LONG RUN: SORENESS OR INJURY?

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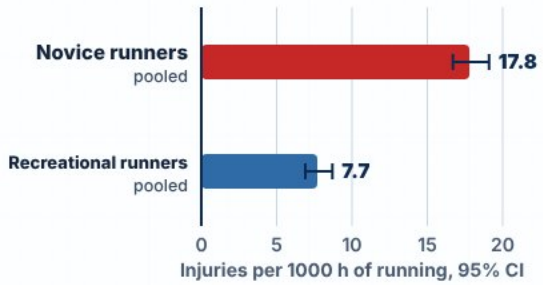


2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip angle from pose landmarks in the side view (trunk line to thigh). Educational, not diagnostic.

Soreness: general, delayed, easing

- Easy walking on the flat, lead hip flexed ≈**23°** at heel contact: a low-load test — generalised soreness usually allows a normal, even stride.
- Soreness builds over hours and peaks at 48–72 h. Sudden, sharp, localised pain that began during the run suggests a structural muscle injury.

New runners are injured more



Meta-analysis, 13 studies; single-study range 2.5–33.0 per 1000 h. Videbæk et al. (2015).

Myth: "Sore two days later means I tore something." Delayed, generalised soreness fits DOMS, with no fibre tear.

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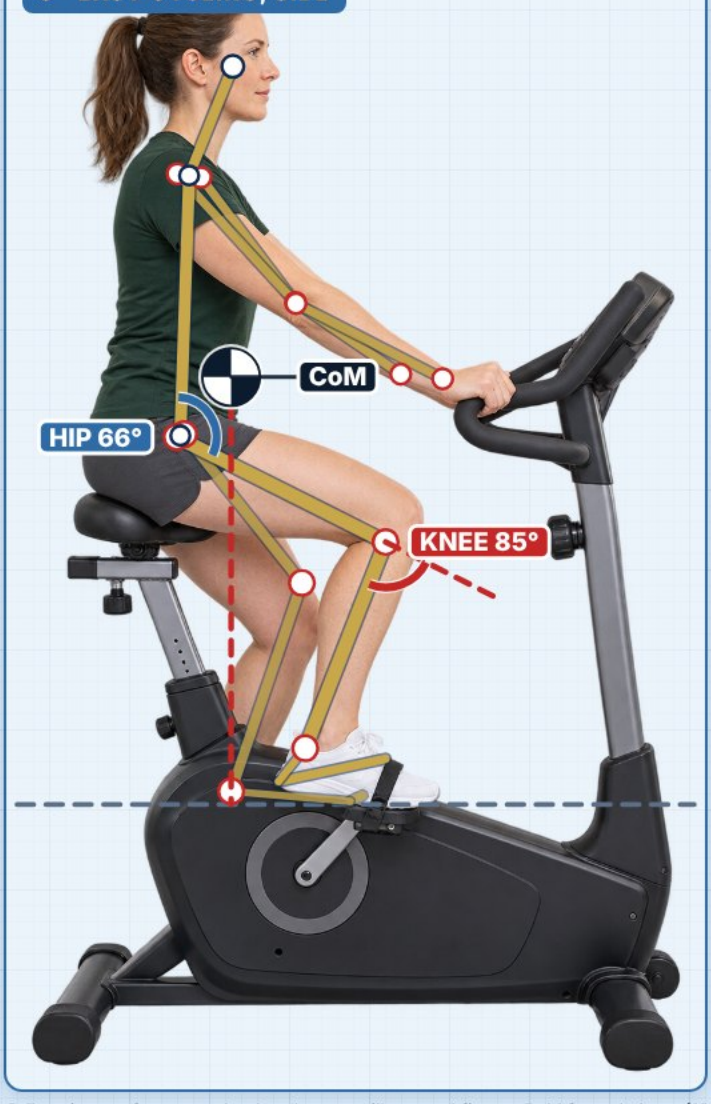
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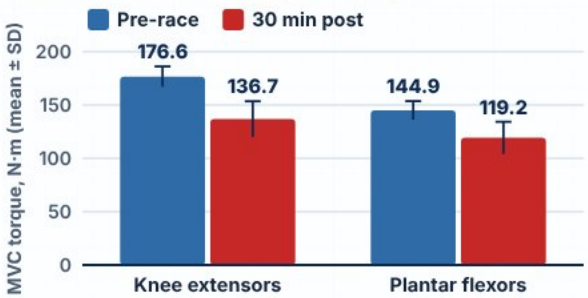
C · EASY CYCLING, SIDE



Easy cycling as active recovery

- Upright on a stationary bike, hip flexed ≈**66°** and knee ≈**85°** at the top of the stroke: low-impact, mostly concentric work for tired thighs.
- Active recovery reduced soreness in pooled trials (SMD −0.94); after a marathon, knee extensor strength was 22% down at 30 minutes.

A marathon drains thigh strength



8 elite runners, tested 1 week before and 30 min after a marathon. Petersen et al. (2007). Active recovery: Dupuy et al. (2018).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

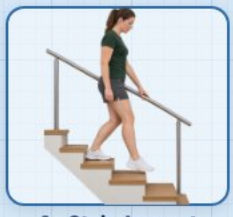
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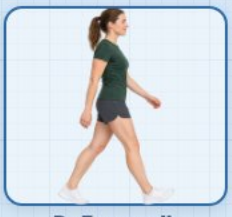
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THIGH PAIN AFTER A LONG RUN: SORENESS OR INJURY?

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A · Stair descent
Trailing knee ≈38°

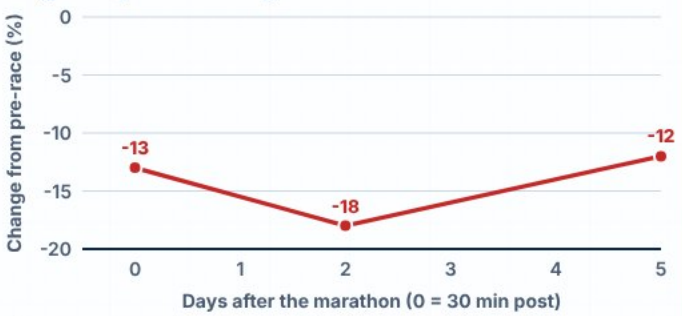


B · Easy walk
Normal stride?



C · Easy cycling
Active recovery

Legs stay flat for days



Countermovement jump power at 30 min, day 2 and day 5; 8 elite runners. Petersen et al. (2007).

Decision pathway

1. **CHECK**
   Generalised ache, slow onset, peak at 48–72 h: likely soreness. Sharp, local, sudden: assess for injury.
2. **RECOVER**
   Use easy walking or cycling, massage or compression; stretching did not reduce soreness.
3. **RETURN**
   Resume hard running once strength and spring return; expect several days after a marathon.

NOT RECOMMENDED

Racing or speed work on legs that are still heavy, or stretching hard to "flush" soreness.

SEEK ASSESSMENT IF

Severe pain with swelling or weakness, dark urine, pain that worsens with each run, or pain on hopping.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Dupuy, O., Douzi, W., Theurot, D., Bosquet, L., & Dugué, B. (2018). An evidence-based approach for choosing post-exercise recovery techniques to reduce markers of muscle damage, soreness, fatigue, and inflammation: A systematic review with meta-analysis. *Frontiers in Physiology, 9*, 403. https://doi.org/10.3389/fphys.2018.00403

Hotfiel, T., Freiwald, J., Hoppe, M. W., Lutter, C., Forst, R., Grim, C., Bloch, W., Huettel, M., & Heiss, R. (2018). Advances in delayed-onset muscle soreness (DOMS): Part I: Pathogenesis and diagnostics. *Sportverletzung · Sportschaden, 32*(4), 243–250. https://doi.org/10.1055/a-0753-1884

Mueller-Wohlfahrt, H.-W., Haensel, L., Mithoefer, K., Ekstrand, J., English, B., McNally, S., Orchard, J., van Dijk, C. N., Kerkhoffs, G. M., Schamasch, P., Blottner, D., Swaerd, L., Goedhart, E., & Ueblacker, P. (2013). Terminology and classification of muscle injuries in sport: The Munich consensus statement. *British Journal of Sports Medicine, 47*(6), 342–350. https://doi.org/10.1136/bjsports-2012-091448

Petersen, K., Hansen, C. B., Aagaard, P., & Madsen, K. (2007). Muscle mechanical characteristics in fatigue and recovery from a marathon race in highly trained runners. *European Journal of Applied Physiology, 101*(3), 385–396. https://doi.org/10.1007/s00421-007-0504-x

Samuel, D., Rowe, P., Hood, V., & Nicol, A. (2011). The biomechanical functional demand placed on knee and hip muscles of older adults during stair ascent and descent. *Gait & Posture, 34*(2), 239–244. https://doi.org/10.1016/j.gaitpost.2011.05.005

Scalco, R. S., Snoeck, M., Quinlivan, R., Treves, S., Laforét, P., Jungbluth, H., & Voermans, N. C. (2016). Exertional rhabdomyolysis: Physiological response or manifestation of an underlying myopathy? *BMJ Open Sport & Exercise Medicine, 2*(1), e000151. https://doi.org/10.1136/bmjsem-2016-000151

Videbæk, S., Bueno, A. M., Nielsen, R. O., & Rasmussen, S. (2015). Incidence of running-related injuries per 1000 h of running in different types of runners: A systematic review and meta-analysis. *Sports Medicine, 45*(7), 1017–1026. https://doi.org/10.1007/s40279-015-0333-8

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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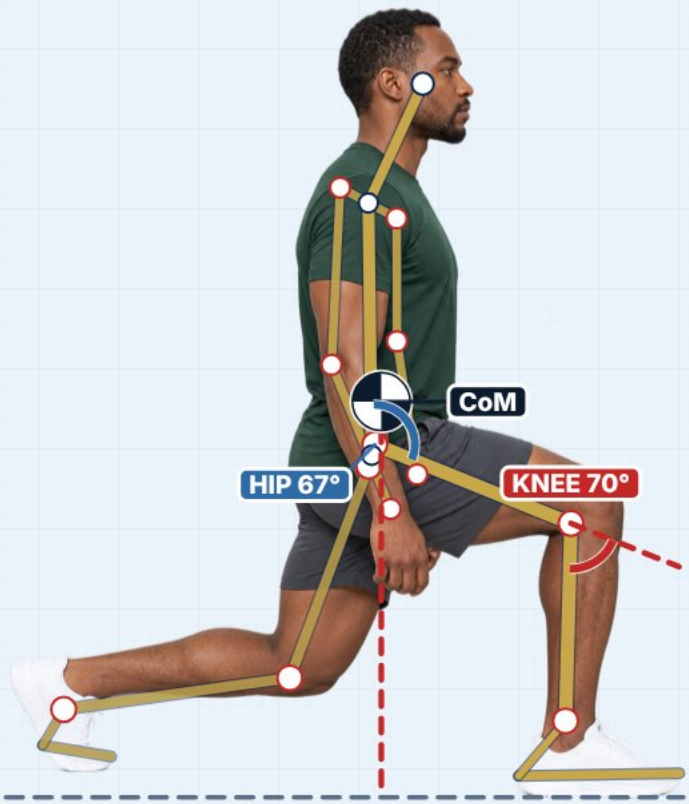
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DOMS IN THE THIGHS: WHY ECCENTRIC WORK HURTS DAYS LATER

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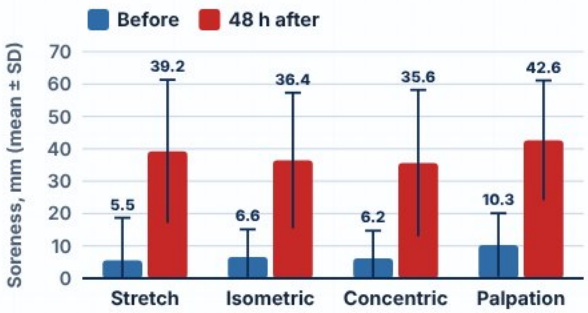
A · LOWERING INTO LUNGE, SIDE



Lowering is lengthening

- Lowering slowly into a lunge, trunk upright, front knee ≈**70°**: the quadriceps lengthen while braking the descent — eccentric work, the type that provokes DOMS.
- Two days after 60 maximal eccentric knee-extensor contractions, the thigh hurt when stretched, contracted or pressed.

Every provocation hurts at 48 h



Visual analogue scale; 56 sedentary young men; 6 × 10 maximal eccentric contractions at 60°/s. Konrad et al. (2022).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Front-knee angle from hip, knee and ankle landmarks in the side view. Educational, not diagnostic.

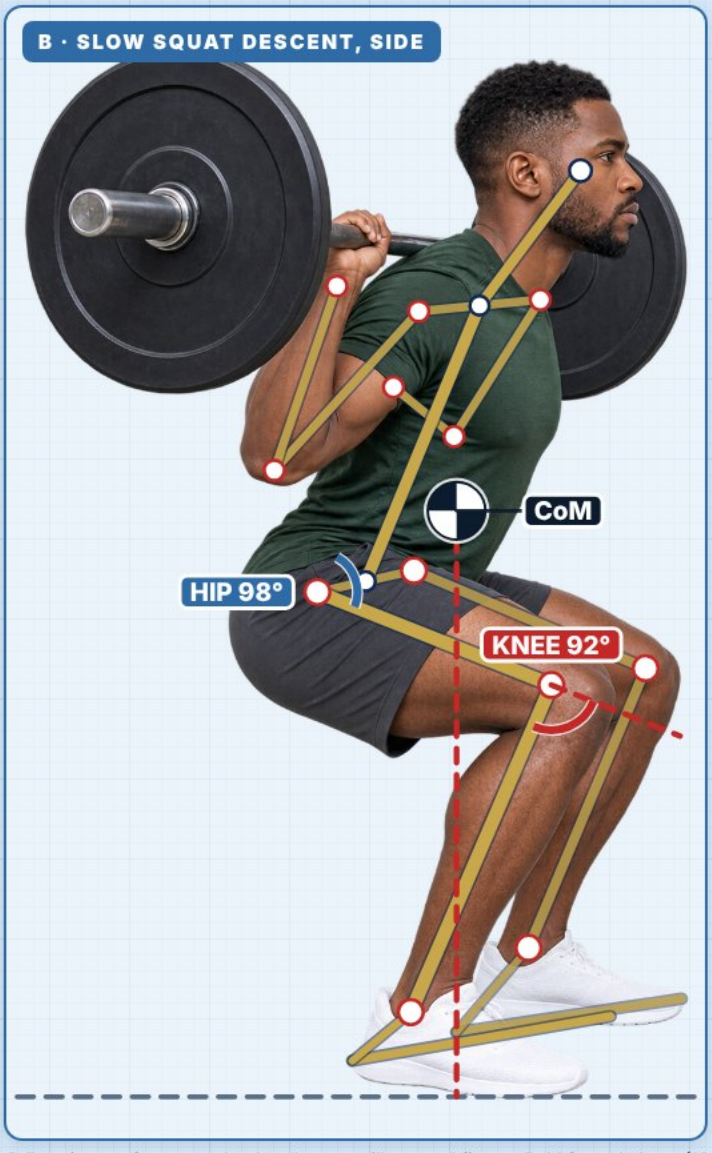
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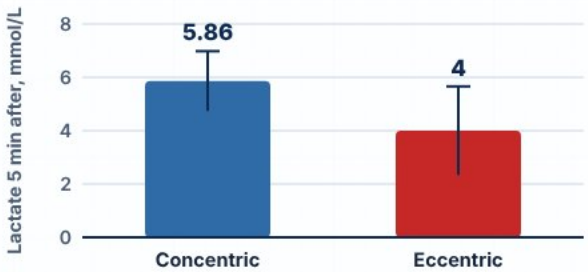
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Easy now, sore later

- Slow squat descent under a barbell, hip ≈**98°** and knee ≈**92°**: eccentric lowering produces high force at a lower metabolic cost.
- Eccentric sets gave lower heart rate, ventilation and lactate than concentric sets, yet this is the work that brings soreness 48–72 h later.

Less lactate, not more



12 sedentary men, 3 × 12 maximal isokinetic reps at 60°/s; mean ± SD. Paulus et al. (2019).

Myth: "DOMS is lactic acid." Eccentric work made less lactate, and soreness peaks days later, not during exercise.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view; bar load not shown in the analysis. Educational, not diagnostic.

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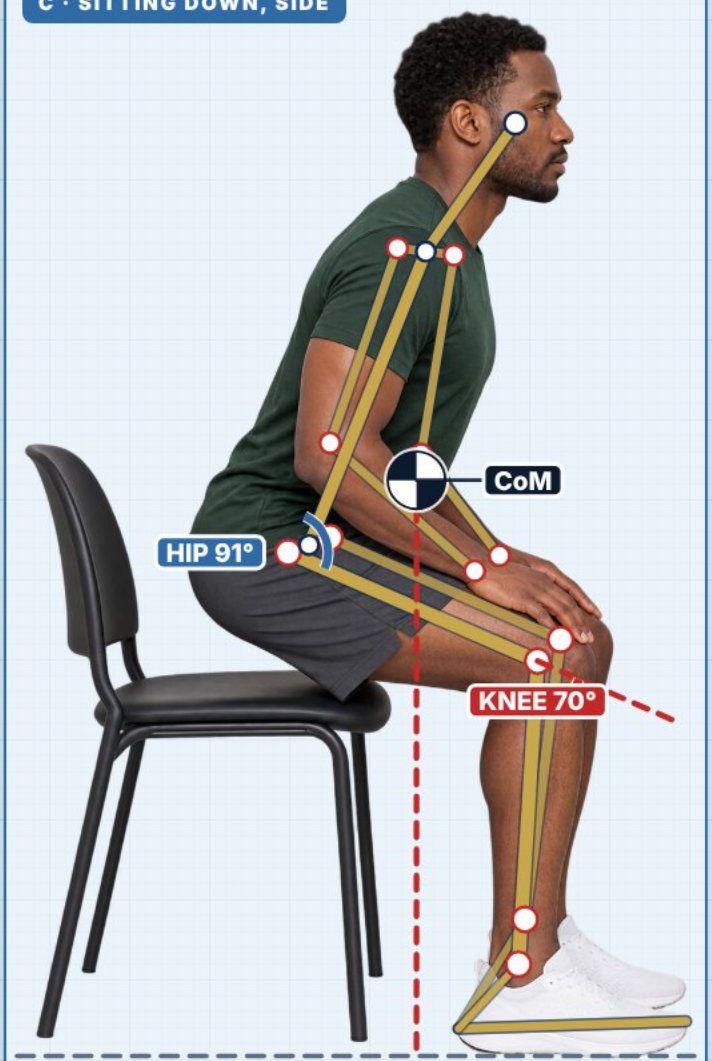
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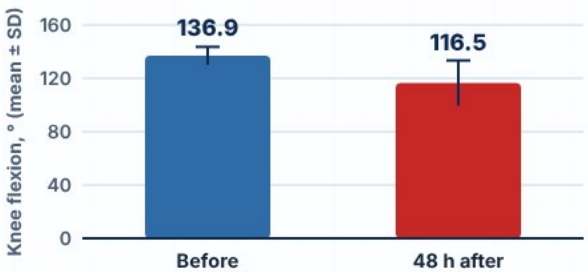
C · SITTING DOWN, SIDE



Why sitting down is the test

- Lowering carefully onto a chair, hands on the thighs, knee ≈**70°**: the sore quadriceps must lengthen under body weight, and the hands share the load.
- At 48 h, knee range fell and isometric strength was about a third lower (159.4 to 104.5 N·m), so heavy or fast work is done with reduced capacity.

Stiffer knee at 48 hours



Knee flexion range of motion; same 56 men; loss of range correlated with greater tissue hardness. Konrad et al. (2022).

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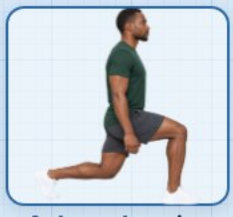
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A · Lunge lowering
Knee ≈70°

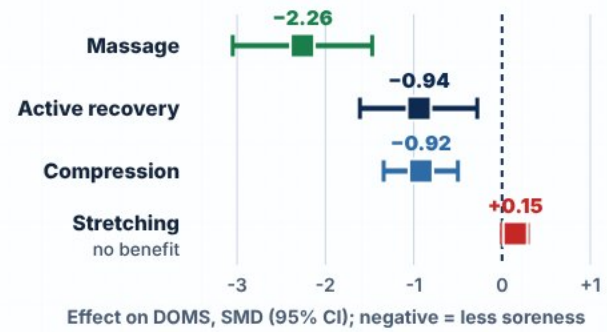


B · Squat descent
Knee ≈92°



C · Sitting down
Knee ≈70°

What eases the soreness



Effect on DOMS, SMD (95% CI); negative = less soreness

Systematic review with meta-analysis of post-exercise recovery techniques. Dupuy et al. (2018).

Decision pathway

1. **DOSE**
   Introduce lunges, squats and Nordics at a low eccentric dose; the repeated-bout effect makes the next session hurt less.
2. **RECOVER**
   Use massage, easy movement or compression; stretching did not reduce soreness.
3. **PLAN**
   Avoid maximal or high-speed work at the 48–72 h peak, when strength and range are down.

NOT RECOMMENDED

Training through severe soreness at full intensity, or treating DOMS as a sign of good progress.

SEEK ASSESSMENT IF

Severe pain with swelling or weakness, dark urine after very hard exercise, or sharp localised pain felt during the exercise.

REFERENCES (APA 7)

Chen, T. C., Yang, T.-J., Huang, M.-J., Wang, H.-S., Tseng, K.-W., Chen, H.-L., & Nosaka, K. (2019). Damage and the repeated bout effect of arm, leg, and trunk muscles induced by eccentric resistance exercises. *Scandinavian Journal of Medicine & Science in Sports, 29*(5), 725–735. https://doi.org/10.1111/sms.13388

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Dupuy, O., Douzi, W., Theurot, D., Bosquet, L., & Dugué, B. (2018). An evidence-based approach for choosing post-exercise recovery techniques to reduce markers of muscle damage, soreness, fatigue, and inflammation: A systematic review with meta-analysis. *Frontiers in Physiology, 9*, 403. https://doi.org/10.3389/fphys.2018.00403

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Konrad, A., Kasahara, K., Yoshida, R., Yahata, K., Sato, S., Murakami, Y., Aizawa, K., & Nakamura, M. (2022). Relationship between eccentric-exercise-induced loss in muscle function to muscle soreness and tissue hardness. *Healthcare, 10*(1), 96. https://doi.org/10.3390/healthcare10010096

Mueller-Wohlfahrt, H.-W., Haensel, L., Mithoefer, K., Ekstrand, J., English, B., McNally, S., Orchard, J., van Dijk, C. N., Kerkhoffs, G. M., Schamasch, P., Blottner, D., Swaerd, L., Goedhart, E., & Ueblacker, P. (2013). Terminology and classification of muscle injuries in sport: The Munich consensus statement. *British Journal of Sports Medicine, 47*(6), 342–350. https://doi.org/10.1136/bjsports-2012-091448

Paulus, J., Croisier, J.-L., Kaux, J.-F., & Bury, T. (2019). Eccentric versus concentric: Which is the most stressful cardiovascularly and metabolically? *Current Sports Medicine Reports, 18*(12), 477–489. https://doi.org/10.1249/JSR.0000000000000666

Scalco, R. S., Snoeck, M., Quinlivan, R., Treves, S., Laforét, P., Jungbluth, H., & Voermans, N. C. (2016). Exertional rhabdomyolysis: Physiological response or manifestation of an underlying myopathy? *BMJ Open Sport & Exercise Medicine, 2*(1), e000151. https://doi.org/10.1136/bmjsem-2016-000151

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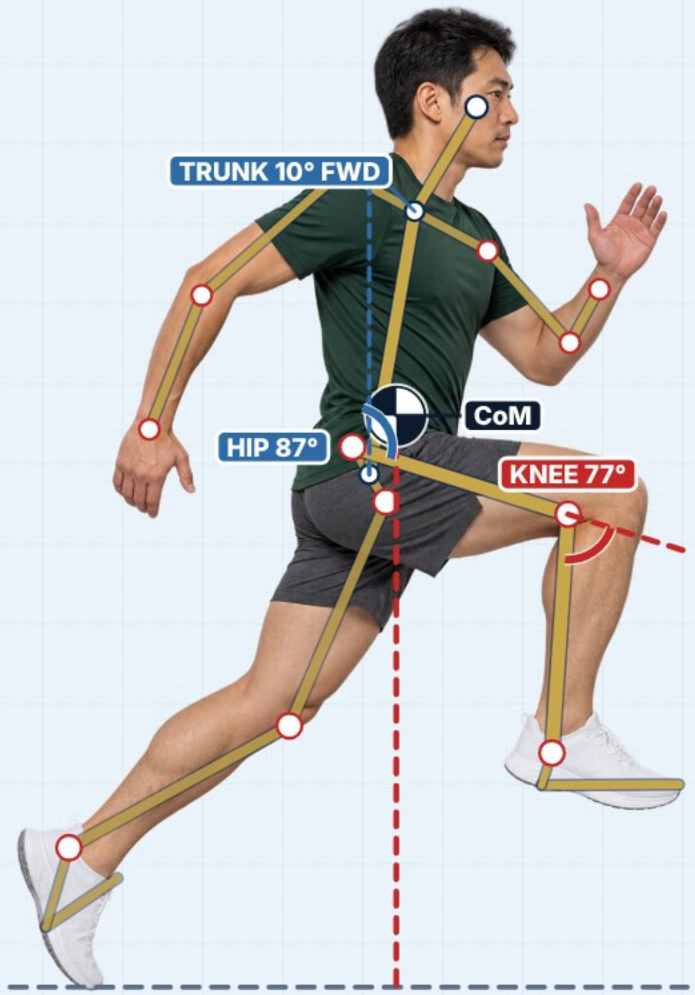
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SPRINTING TECHNIQUE AND HAMSTRING LOAD: POSTURE, STRIDE AND PELVIS

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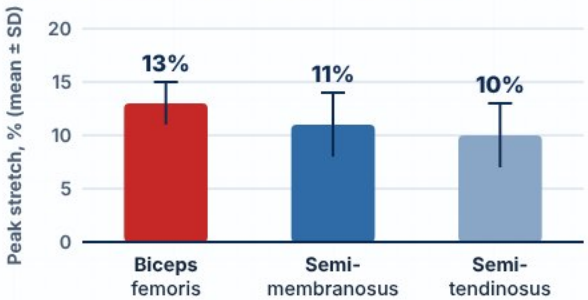
A · TOP-SPEED SPRINT, SIDE



Tall posture, knee high in front

- Airborne at top speed with the trunk **10°** forward of vertical and the front hip flexed **87°**, knee **77°**: the thigh is driven up before the shank swings out.
- In simulations at 80–100% of maximum speed, the hamstrings lengthened under load from 50% to 90% of the stride cycle, and biceps femoris was stretched furthest.

Peak stretch beyond upright length



12 runners at 80–100% of maximum speed; musculoskeletal simulation, peak length vs upright standing. Chumanov et al. (2011).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk, hip and knee angles from pose landmarks in the side view; airborne sprint poses are approximate. Educational, not diagnostic.

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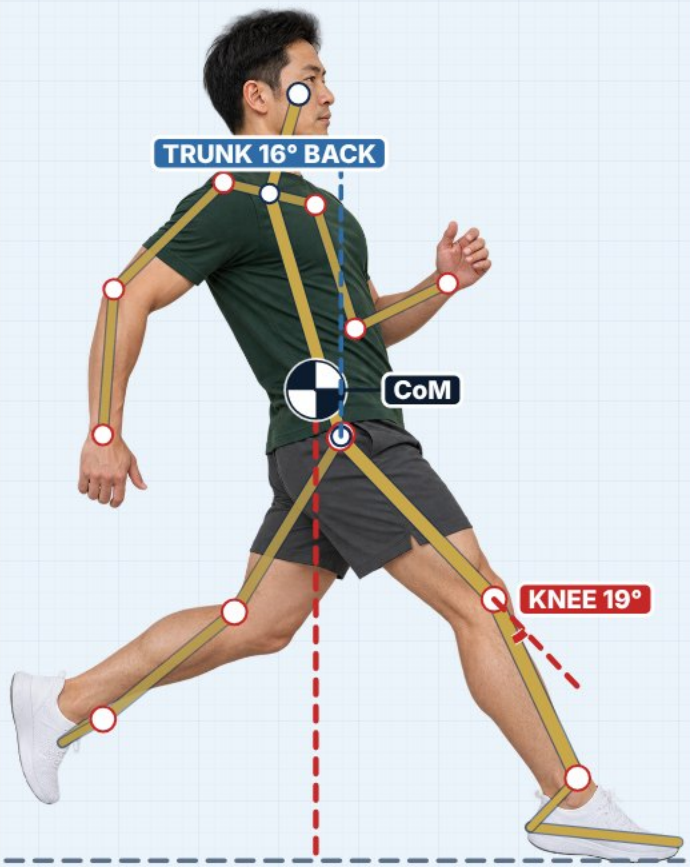
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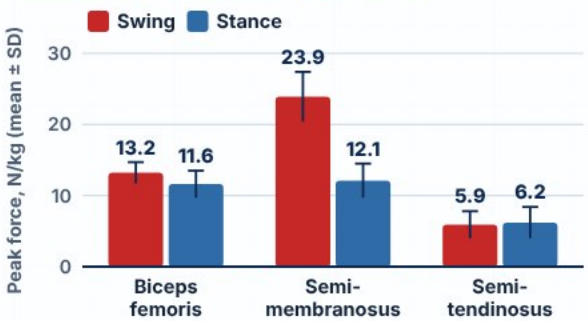
B · OVERSTRIDE, SIDE



Foot far ahead, knee nearly straight

- The front foot lands well ahead of the body with the knee flexed only **19°** and the trunk **16°** behind vertical: the leg reaches out instead of landing under the hips.
- The hamstrings peak in late swing as the leg reaches forward; at top speed, swing-phase force exceeded stance force in biceps femoris and semimembranosus.

Hamstring force: swing vs stance



12 runners at 100% sprint speed; forward-dynamic simulation, force per kg body mass. Chumanov et al. (2011).

Myth: "Overstriding is the proven cause of hamstring strain." No study in our evidence set tested it directly; late-swing load and pelvis–trunk control are the documented links.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line from hip to shoulder points; knee angle in the side view. Educational, not diagnostic.

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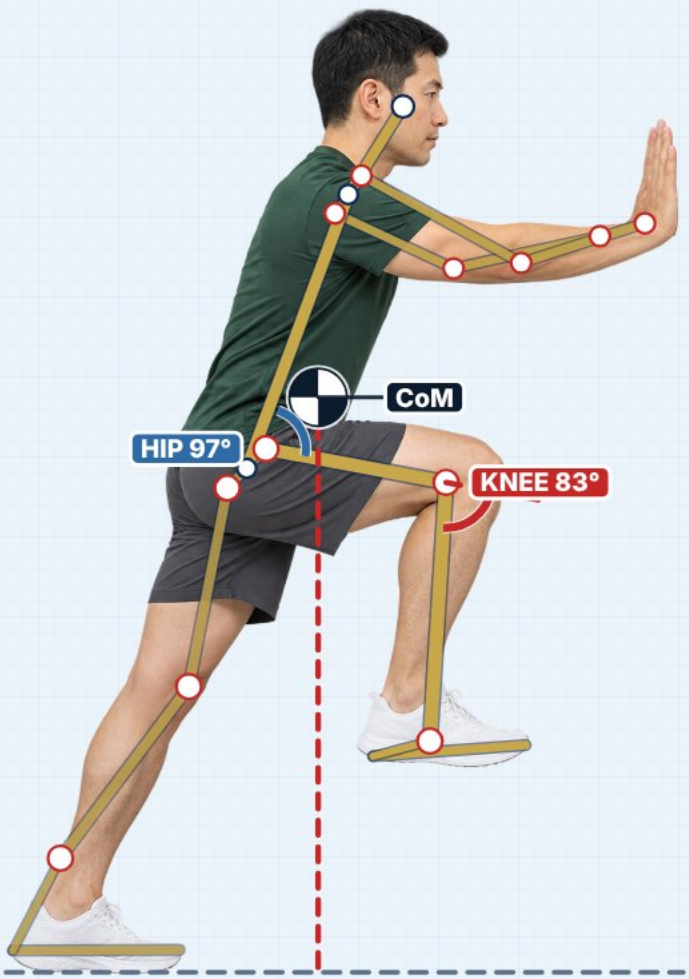
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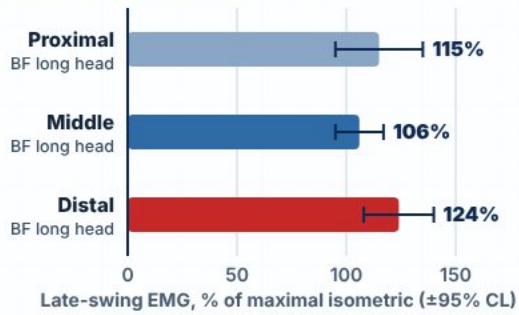
C · WALL-DRIVE DRILL, SIDE



Drilling the drive position

- Wall-drive position, arm braced forward (wall not shown): standing tall on the left leg with the right hip flexed **97°** and knee **83°**, trunk and pelvis held steady.
- Each 10% rise in gluteus maximus activity in front swing was associated with 20% lower hamstring injury risk, and trunk activity in backswing with 6% lower risk.

Fast running is a maximal effort



13 runners at 6.8 m/s; high-density EMG of biceps femoris long head (BF). Hegyi et al. (2019).

Key point: drills rehearse posture, but sprinting itself drives the hamstrings beyond a maximal contraction, so plan real sprint exposure.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Risk figures: Schuermans, Danneels et al. (2017). Educational, not diagnostic.

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INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

SPRINTING TECHNIQUE AND HAMSTRING LOAD: POSTURE, STRIDE AND PELVIS

AN MMSX AUTHORITY | APPLIED BIOMECHANICS LAB EDUCATIONAL ANALYSIS



A · Top speed
Hip 87°, trunk 10°



B · Overstride
Knee 19°



C · Wall drive
Hip 97°

Top-speed exposure: lower injury odds



37 elite Gaelic footballers, one season, all injury types; no CIs reported. Malone et al. (2017).

Decision pathway

1. **POSTURE**
   Coach a tall trunk and level pelvis at speed; pelvis and trunk motion in swing were linked to later injury.
2. **STRIDE**
   Cue the foot to land closer under the hips; a 6-week programme changed sprint kinematics.
3. **EXPOSE**
   Plan regular, progressive running at near-maximal speed rather than avoiding it.

NOT RECOMMENDED

Avoiding top-speed running altogether; changing technique abruptly just before matches.

SEEK ASSESSMENT IF

Sudden sharp pain in the back of the thigh mid-sprint with immediate inability to continue: a likely structural muscle injury.

REFERENCES (APA 7)

Chumanov, E. S., Heiderscheit, B. C., & Thelen, D. G. (2011). Hamstring musculotendon dynamics during stance and swing phases of high-speed running. *Medicine and Science in Sports and Exercise, 43*(3), 525–532. https://doi.org/10.1249/MSS.0b013e3181f23fe8

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Hegyi, A., Gonçalves, B. A., Finni, T., & Cronin, N. J. (2019). Individual region- and muscle-specific hamstring activity at different running speeds. *Medicine & Science in Sports & Exercise, 51*(11), 2274–2285. https://doi.org/10.1249/MSS.0000000000002060

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. (2017). High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *Journal of Science and Medicine in Sport, 20*, 250–254. https://doi.org/10.1016/j.jsams.2016.08.005

Mendiguchia, J., Castaño-Zambudio, A., Jiménez-Reyes, P., Morin, J.-B., Edouard, P., Conceição, F., Dodoo, J., & Colyer, S. (2022). Can we modify maximal speed running posture? Implications for performance and hamstring injury management. *International Journal of Sports Physiology and Performance, 17*(3), 374–383. https://doi.org/10.1123/ijspp.2021-0107

Schuermans, J., Danneels, L., Van Tiggelen, D., Palmans, T., & Witvrouw, E. (2017). Proximal neuromuscular control protects against hamstring injuries in male soccer players: A prospective study with electromyography time-series analysis during maximal sprinting. *The American Journal of Sports Medicine, 45*(6), 1315–1325. https://doi.org/10.1177/0363546516687750

Schuermans, J., Van Tiggelen, D., Palmans, T., Danneels, L., & Witvrouw, E. (2017). Deviating running kinematics and hamstring injury susceptibility in male soccer players: Cause or consequence? *Gait & Posture, 57*, 270–277. https://doi.org/10.1016/j.gaitpost.2017.06.268

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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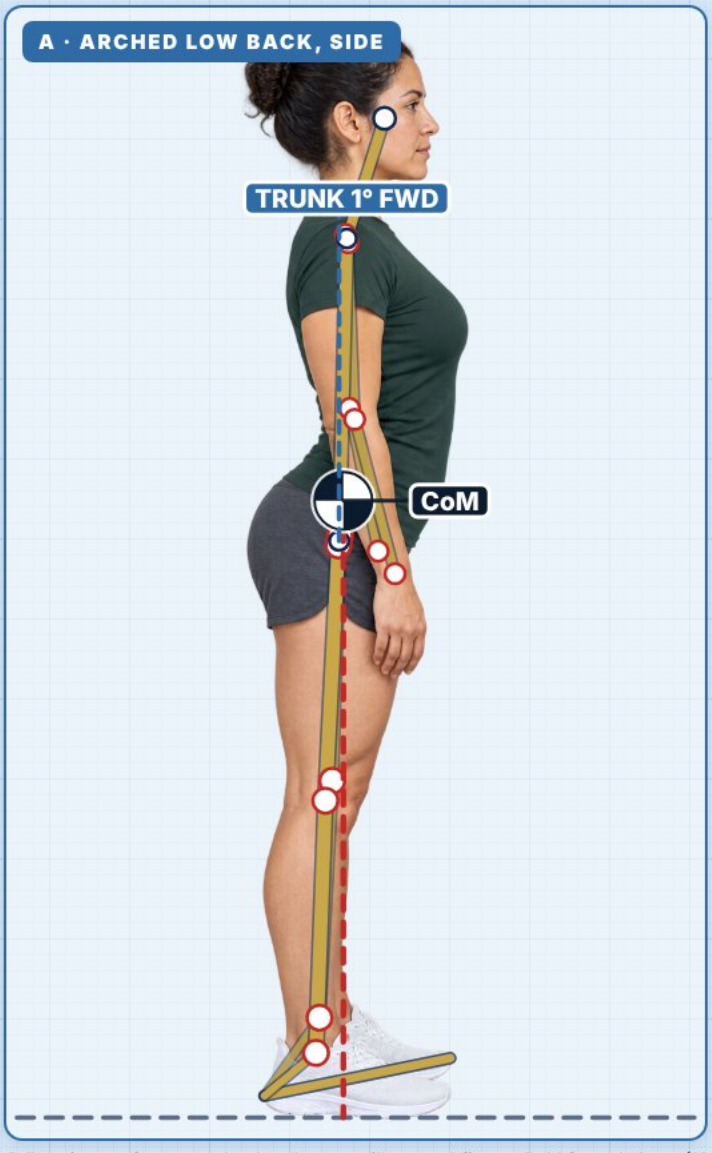
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PELVIC TILT AND HAMSTRING STRAIN: DOES THE PELVIS MATTER?

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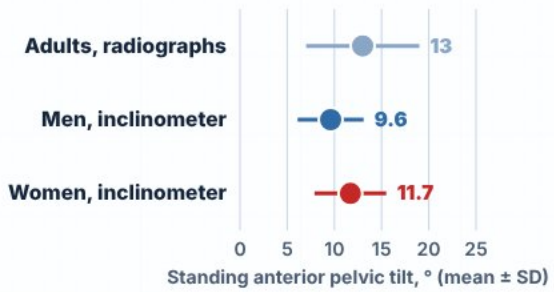


2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk line from hip to shoulder points in the side view. Educational, not diagnostic.

An arched back is not a fault by itself

- Standing with the lower back arched and the buttocks pushed back: the pelvis is tipped forward, which moves the sitting bone, where the hamstrings arise, up and back.
- Some forward tilt is normal when standing: average values of about 9–13° are reported, with women averaging more than men.

Normal standing pelvic tilt



Asymptomatic adults (radiographs) and adults measured by inclinometer; secondary summary. Suits (2021).

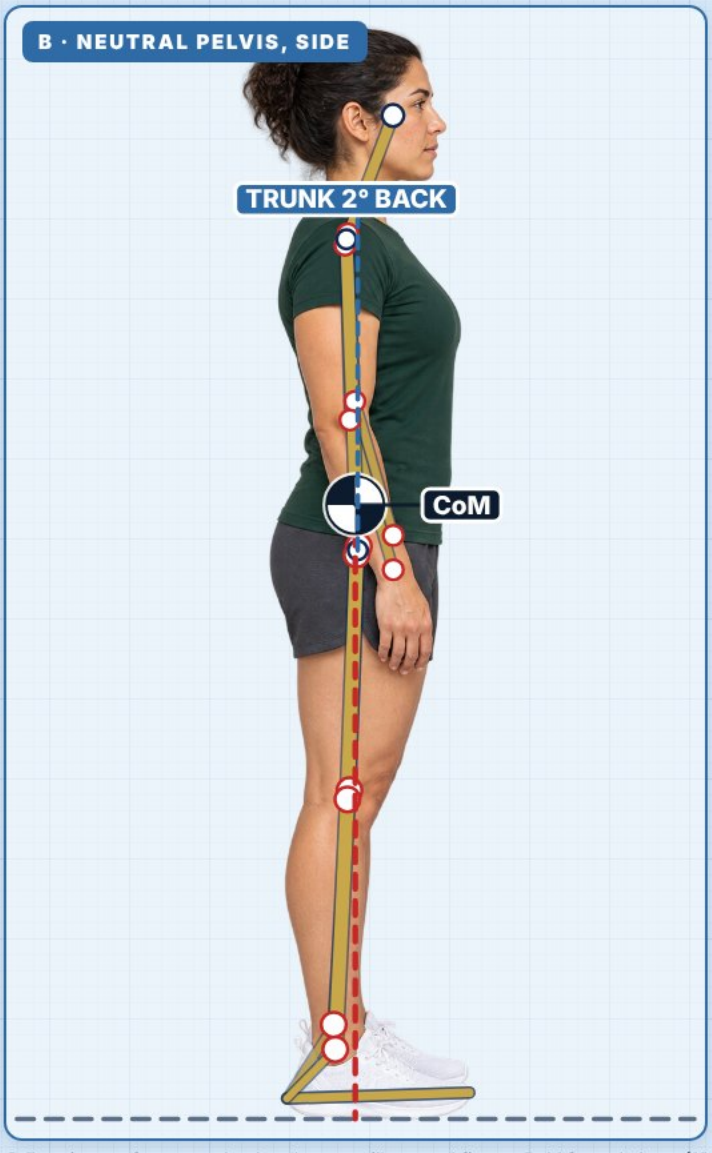
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Neutral: hard to tell apart by eye

- Relaxed standing with a neutral pelvis. In both photos the hip-to-shoulder trunk line sits within **3°** of vertical, so the visible difference lies in the lower back, not the trunk.
- Pelvic bones themselves vary: the angle between the front and back pelvic landmarks ranged from 0° to 23° across 30 pelves (mean 13°, SD 5°).

Bone shape alone changes the "tilt"



30 cadaver pelves; ASIS–PSIS line angle and side-to-side difference. Preece et al. (2008).

Key point: two people with the same true pelvic position can look very different, so a posture photo cannot diagnose risky tilt.

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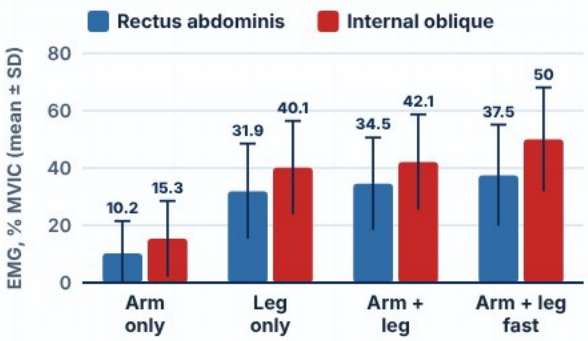
C · DEAD BUG, SIDE



Dead bug: pelvis still, hip moving

- Lying on her back, one arm reaching to the ceiling and the other overhead, one hip and knee bent to 90° and the other leg extended just above the floor.
- Moving a leg is what loads the trunk: leg movement roughly tripled abdominal activity compared with arm movement only, and faster tempo raised it further.

Leg movement drives abdominal demand



30 healthy adults; 90 bpm, fast = 120 bpm; MVIC = maximal voluntary isometric contraction. Yun et al. (2017).

Myth: "A forward-tilted pelvis means your hamstrings will tear." Previous injury and age are the strongest identified risk factors.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmark angles: pose detection is unreliable for lying poses. Educational, not diagnostic.

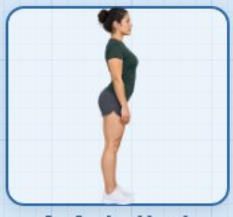
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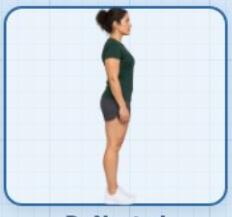
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A · Arched back
Normal range likely

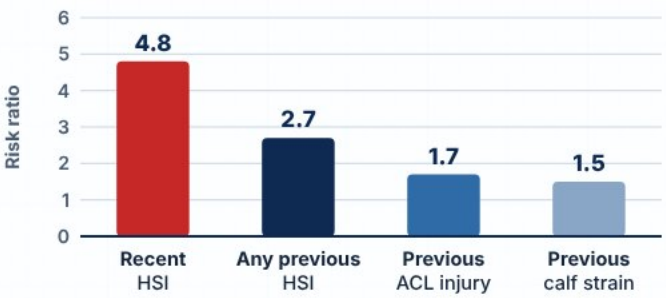


B · Neutral
Trunk within 3°



C · Dead bug
Pelvis held still

History outweighs posture



Risk ratio for hamstring strain injury (HSI); 78 studies, 71,324 athletes; all p ≤ 0.002. Green et al. (2020).

Decision pathway

1. **SCREEN**
   Ask about previous hamstring injury first; a recent injury carried the highest risk.
2. **TRAIN**
   Train pelvic and trunk control at speed; a 6-week programme reduced pelvic tilt in gait.
3. **KEEP PERSPECTIVE**
   Forward tilt in sprint swing was linked to later injury; standing posture was not shown to be.

NOT RECOMMENDED

Diagnosing hamstring risk from a standing posture photo; posture correction in place of strength and sprint work.

SEEK ASSESSMENT IF

Low back pain with leg pain, numbness or weakness alongside "hamstring" symptoms: a spinal or nerve source needs assessment.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Green, B., Bourne, M. N., van Dyk, N., & Pizzari, T. (2020). Recalibrating the risk of hamstring strain injury (HSI): A 2020 systematic review and meta-analysis of risk factors for index and recurrent hamstring strain injury in sport. *British Journal of Sports Medicine, 54*(18), 1081–1088. https://doi.org/10.1136/bjsports-2019-100983

Mendiguchia, J., González de la Flor, A., Mendez-Villanueva, A., Morin, J.-B., Edouard, P., & Garrues, M. A. (2021). Training-induced changes in anterior pelvic tilt: Potential implications for hamstring strain injuries management. *Journal of Sports Sciences, 39*(7), 760–767. https://doi.org/10.1080/02640414.2020.1845439

Preece, S., Willan, P., Nester, C., Graham-Smith, P., Herrington, L., & Bowker, P. (2008). Variation in pelvic morphology may prevent the identification of anterior pelvic tilt. *Journal of Manual & Manipulative Therapy, 16*, 113–117.

Schuermans, J., Van Tiggelen, D., Palmans, T., Danneels, L., & Witvrouw, E. (2017). Deviating running kinematics and hamstring injury susceptibility in male soccer players: Cause or consequence? *Gait & Posture, 57*, 270–277. https://doi.org/10.1016/j.gaitpost.2017.06.268

Suits, W. H. (2021). Clinical measures of pelvic tilt in physical therapy. *International Journal of Sports Physical Therapy, 16*(5), 1366–1375. https://doi.org/10.26603/001c.27978

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

Yun, B.-G., Lee, S.-J., So, H.-J., & Shin, W.-S. (2017). Changes in muscle activity of the abdominal muscles according to exercise method and speed during dead bug exercise. *Physical Therapy Rehabilitation Science, 6*(1), 1–6. https://doi.org/10.14474/ptrs.2017.6.1.1

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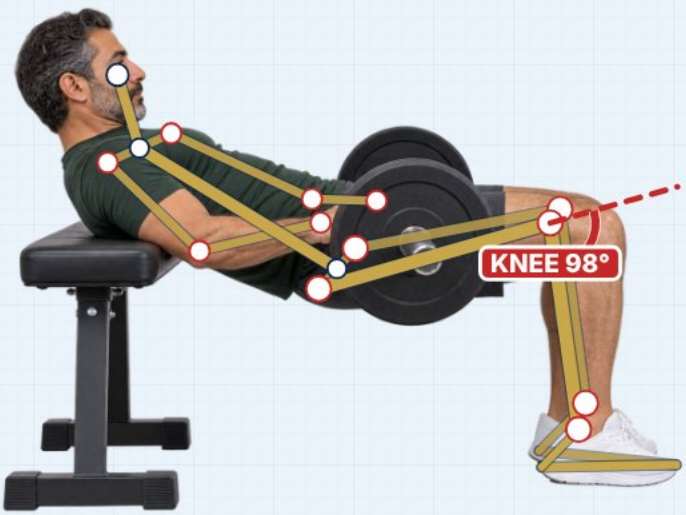
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GLUTE WEAKNESS AND HAMSTRING OVERLOAD: THE SHARED HIP-EXTENSION JOB

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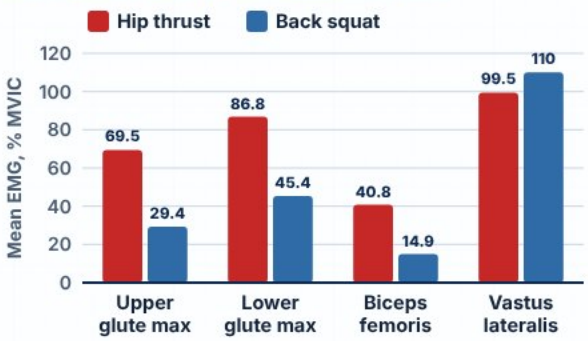
A · BARBELL HIP THRUST, SIDE



Hip thrust: the glutes lead

- Upper back on a bench, barbell across the hips, hips lifted towards the line of the shoulders and knees, knee flexed ≈**98°** with the shin near vertical.
- Compared with the back squat, the hip thrust roughly doubled gluteus maximus activity and also asked more of biceps femoris; vastus lateralis did not differ.

Who does the hip-extension work?



13 trained women, 10-repetition-maximum loads; vastus lateralis difference not significant. Contreras et al. (2015).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle from pose landmarks in the side view; the hip angle was not measured because the bar hides the hip. Educational, not diagnostic.

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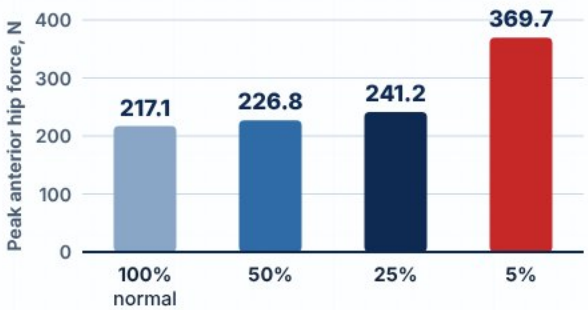
B · GLUTE BRIDGE, SIDE



Bridge: the same job, body weight

- Lying on the mat with the feet flat and the hips lifted, hip still flexed ≈**27°** and knee ≈**115°**: glutes and hamstrings share the lift.
- In a hip model, cutting gluteal force to 5% raised semimembranosus force from 26.5% to 77.9% of its maximum and anterior hip force by 70%.

Weaker glutes, more load elsewhere



Musculoskeletal model of prone hip extension; x-axis = gluteal maximum force, % of normal. Lewis et al. (2007).

Myth: "Your glutes are switched off and must be activated first." Gluteal activity is graded with the task; load it progressively instead.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view; lying poses are approximate. Educational, not diagnostic.

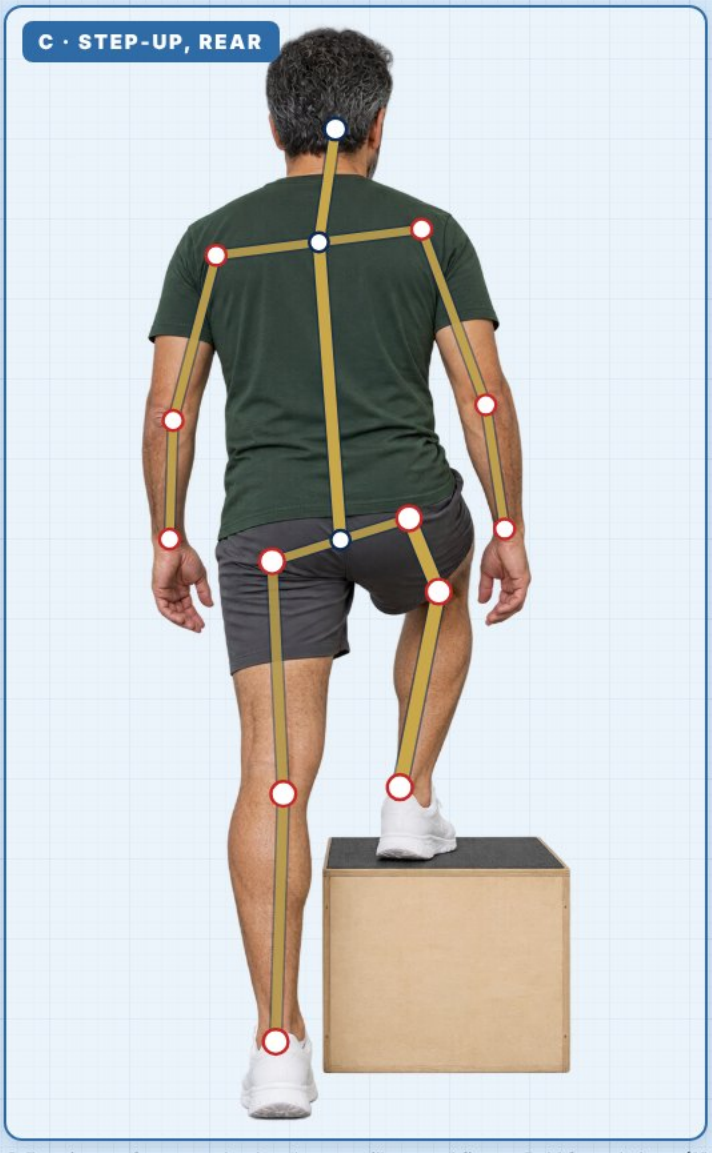
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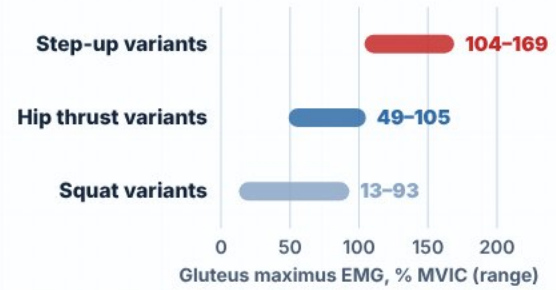
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Step-up: one leg drives the hip

- Seen from behind, the right foot is planted on the box and the left is still on the floor: the right buttock and hamstrings must extend the hip and knee together to rise.
- Across 16 studies, step-up variants produced some of the highest gluteus maximus activity reported, a mean of 125% MVIC.

Which exercises load the glutes most?



Systematic review of 16 studies; ranges rounded to whole numbers; >60% MVIC = very high. Krause Neto et al. (2020).

Key point: a single-leg step-up needs only a box, yet reaches a gluteal demand above that of a maximal test contraction.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Rear view; skeleton only, no angles measured. MVIC = maximal voluntary isometric contraction. Educational, not diagnostic.

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A · Hip thrust
Glutes ≈2× squat

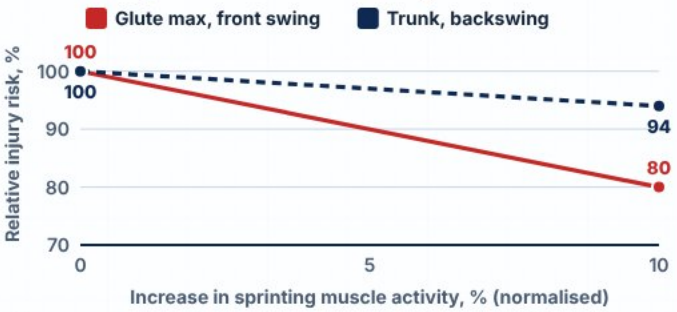


B · Glute bridge
Hip ≈27°



C · Step-up
Mean 125% MVIC

Glutes at speed: lower hamstring risk



60 amateur male footballers, 1.5 seasons; risk change per +10% activity (−20% and −6%). Schuermans, Danneels et al. (2017).

Decision pathway

1. **TRAIN BOTH**
   Load the glutes (hip thrust, step-up) alongside specific hamstring strengthening.
2. **USE IT AT SPEED**
   Carry hip-extension work into sprint drills; gluteal activity while sprinting was linked to lower risk.
3. **KEEP PRIORITIES**
   Previous hamstring injury remains the strongest risk factor; glute work complements, not replaces.

NOT RECOMMENDED

Replacing hamstring strengthening with glute work; long "activation" routines before every session.

SEEK ASSESSMENT IF

Buttock and back-of-thigh pain with numbness, pins and needles or weakness below the knee, or sitting-bone pain worse when sitting.

REFERENCES (APA 7)

Contreras, B., Vigotsky, A. D., Schoenfeld, B. J., Beardsley, C., & Cronin, J. (2015). A comparison of gluteus maximus, biceps femoris, and vastus lateralis electromyographic activity in the back squat and barbell hip thrust exercises. *Journal of Applied Biomechanics, 31*(6), 452–458. https://doi.org/10.1123/jab.2014-0301

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Green, B., Bourne, M. N., van Dyk, N., & Pizzari, T. (2020). Recalibrating the risk of hamstring strain injury (HSI): A 2020 systematic review and meta-analysis of risk factors for index and recurrent hamstring strain injury in sport. *British Journal of Sports Medicine, 54*(18), 1081–1088. https://doi.org/10.1136/bjsports-2019-100983

Krause Neto, W., Soares, E. G., Vieira, T. L., Aguiar, R., Chola, T. A., Sampaio, V. L., & Gama, E. F. (2020). Gluteus maximus activation during common strength and hypertrophy exercises: A systematic review. *Journal of Sports Science and Medicine, 19*(1), 195–203.

Lewis, C. L., Sahrmann, S. A., & Moran, D. W. (2007). Anterior hip joint force increases with hip extension, decreased gluteal force, or decreased iliopsoas force. *Journal of Biomechanics, 40*(16), 3725–3731. https://doi.org/10.1016/j.jbiomech.2007.06.024

Schuermans, J., Danneels, L., Van Tiggelen, D., Palmans, T., & Witvrouw, E. (2017). Proximal neuromuscular control protects against hamstring injuries in male soccer players: A prospective study with electromyography time-series analysis during maximal sprinting. *The American Journal of Sports Medicine, 45*(6), 1315–1325. https://doi.org/10.1177/0363546516687750

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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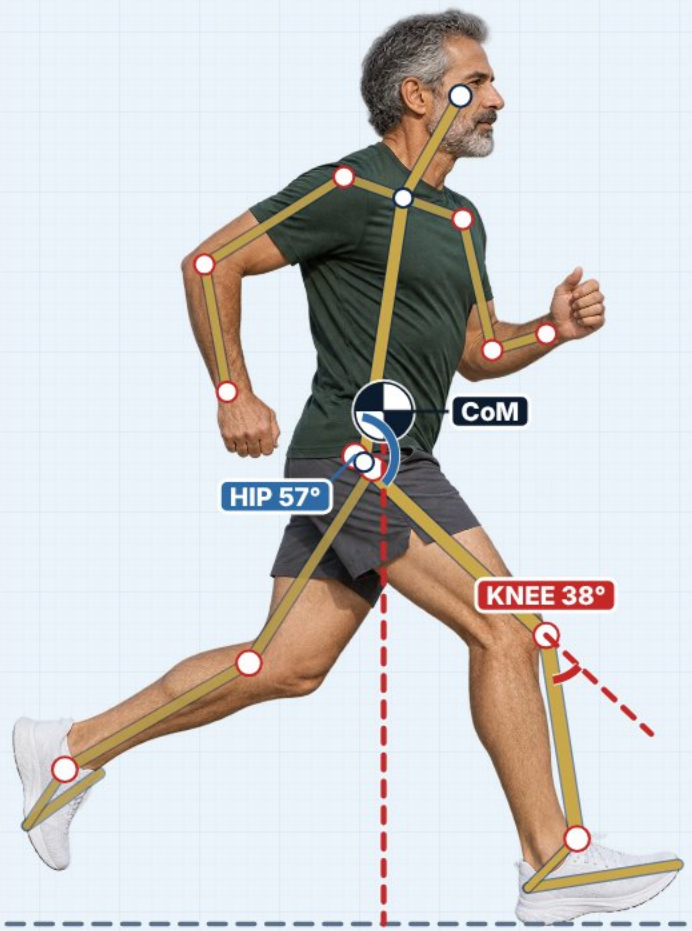
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HAMSTRING INJURIES IN OLDER ATHLETES: MASTERS SPORT AND TENDON HEALTH

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A · FAST RUNNING, SIDE



Older legs, same reaching swing

- A man in his fifties running fast, the right leg reaching forward with the hip flexed **57°** and the knee **38°**: the hamstrings lengthen under load to slow the shank.
- Older age is a consistent risk factor: across 78 studies, injured athletes were older (SMD 1.6, 95% CI 0.6 to 2.6).

Age adds risk in community football



126 community-level Australian footballers, prospective cohort. Gabbe et al. (2005); age SMD from Green et al. (2020).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view; running poses are approximate. Educational, not diagnostic.

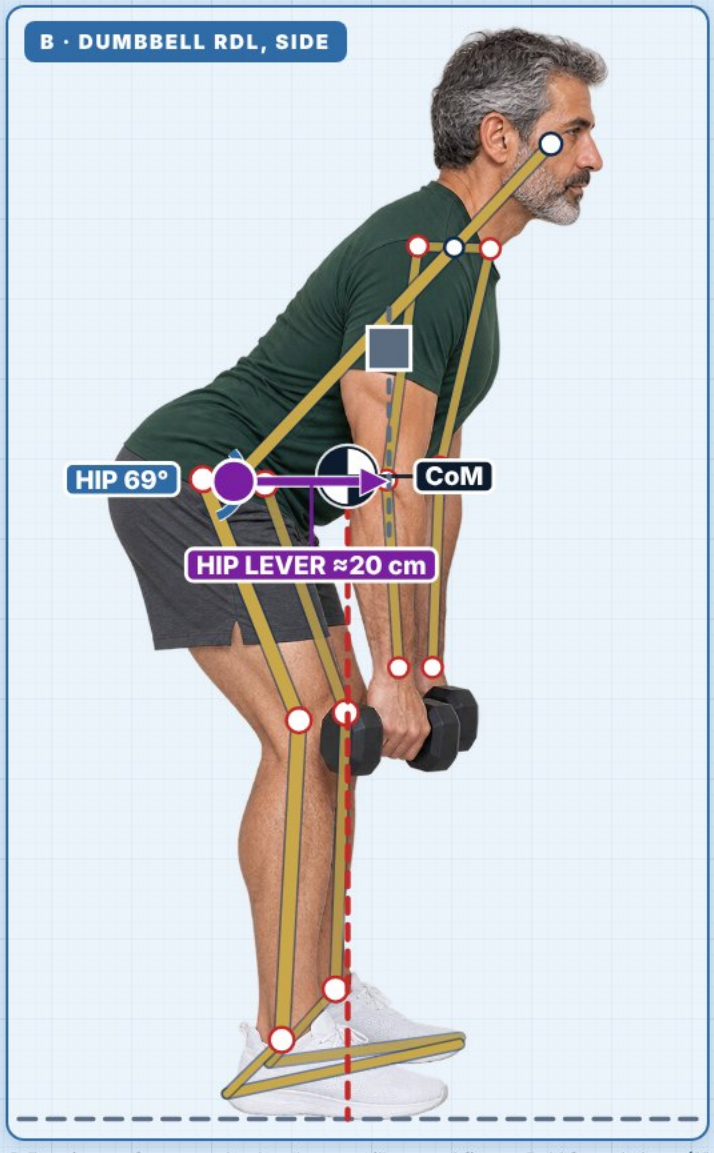
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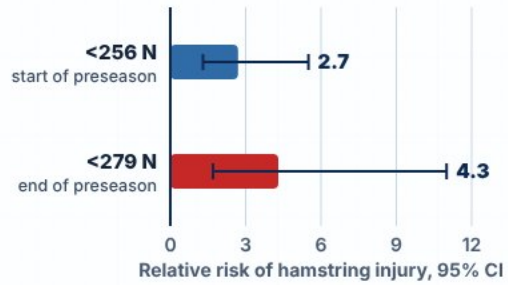
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Romanian deadlift builds the reserve

- Hips back and back flat with the hip flexed **69°**: the upper body acts ≈**20 cm** in front of the hip, ≈**84 N·m** before the dumbbells, held by hamstrings and glutes.
- Low eccentric knee-flexor strength raised future injury risk 2.7–4.3 times, whereas a left–right imbalance above 10% did not.

Low eccentric strength, higher risk



210 elite Australian footballers, 28 new hamstring injuries; Nordic-device force. Opar et al. (2015).

Key point: strength can fall with age and detraining, but unlike age it is measurable and modifiable.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip lever: hip-joint centre to upper-body CoM; moment = upper-body weight × lever, 70 kg adult, static. Dumbbell load not included. Educational, not diagnostic.

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HAMSTRING INJURIES IN OLDER ATHLETES: MASTERS SPORT AND TENDON HEALTH

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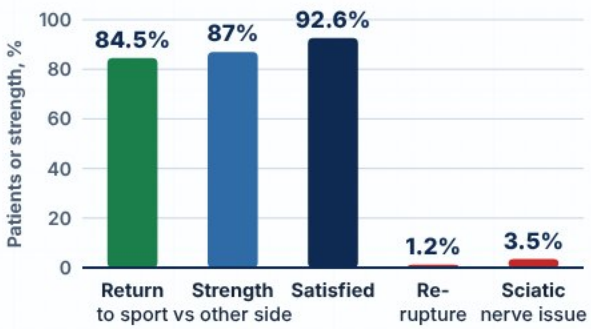
C · SINGLE-LEG BRIDGE, SIDE



Tendon health at the sitting bone

- Lying on his back with the hips lifted on one bent leg and the other leg raised straight: the support-side hamstring and glute work close to the sitting bone.
- Surgically repaired proximal tendon avulsions were most common in mid-life: mean age 44.7 years, with return to sport at a mean of 6.5 months.

After proximal tendon repair



35 studies, 1,530 repaired hamstrings; re-rupture and nerve problems were lower after acute repair. Hillier-Smith & Paton (2022).

Myth: "At my age, hamstring injuries are inevitable, so I should stop sprinting." Age adds risk, but strength is modifiable.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmark angles: pose detection is unreliable for lying poses. Educational, not diagnostic.

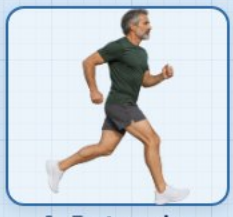
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BIOMECHANICS IS A FORCE-GOVERNED DECISION SYSTEM – NOT A POSTURE MODEL.

INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

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A · Fast running
Hip 57°

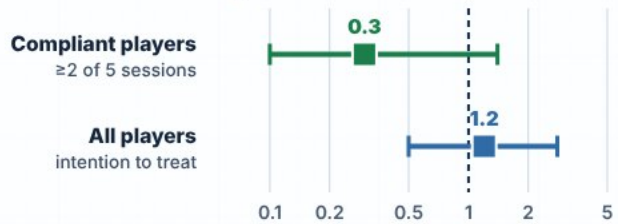


B · Dumbbell RDL
≈84 N·m



C · Single-leg bridge
Tendon loading

Prevention works only if it is done



220 community footballers; 5 eccentric sessions over 12 weeks; 46.8% completed ≥2. Gabbe et al. (2006).

Decision pathway

1. **STRENGTHEN**
   Include the Nordic exercise and eccentric work to tolerance (Grade A and B guidance).
2. **MEASURE**
   Test knee-flexor strength with a dynamometer and track it over the season.
3. **STAY CONSISTENT**
   Choose a short routine that will actually be done; adherence decided the effect.

NOT RECOMMENDED

Giving up sprinting because of age; ambitious programmes that are soon abandoned.

SEEK ASSESSMENT IF

Sudden severe pain high at the back of the thigh near the sitting bone with marked weakness, or new numbness or tingling in the leg.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Gabbe, B. J., Branson, R., & Bennell, K. L. (2006). A pilot randomised controlled trial of eccentric exercise to prevent hamstring injuries in community-level Australian Football. *Journal of Science and Medicine in Sport, 9*, 103–109. https://doi.org/10.1016/j.jsams.2006.02.001

Gabbe, B. J., Finch, C. F., Bennell, K. L., & Wajswelner, H. (2005). Risk factors for hamstring injuries in community level Australian football. *British Journal of Sports Medicine, 39*(2), 106–110. https://doi.org/10.1136/bjsm.2003.011197

Green, B., Bourne, M. N., van Dyk, N., & Pizzari, T. (2020). Recalibrating the risk of hamstring strain injury (HSI): A 2020 systematic review and meta-analysis of risk factors for index and recurrent hamstring strain injury in sport. *British Journal of Sports Medicine, 54*(18), 1081–1088. https://doi.org/10.1136/bjsports-2019-100983

Hillier-Smith, R., & Paton, B. (2022). Outcomes following surgical management of proximal hamstring tendon avulsions: A systematic review and meta-analysis. *Bone & Joint Open, 3*(5), 415–422. https://doi.org/10.1302/2633-1462.35.BJO-2021-0196.R1

Martin, R. L., Cibulka, M. T., Bolgla, L. A., Koc, T. A., Jr., Loudon, J. K., Manske, R. C., Weiss, L., Christoforetti, J. J., & Heiderscheit, B. C. (2022). Hamstring strain injury in athletes: Clinical practice guidelines. *Journal of Orthopaedic & Sports Physical Therapy, 52*(3), CPG1–CPG44. https://doi.org/10.2519/jospt.2022.0301

Opar, D. A., Williams, M. D., Timmins, R. G., Hickey, J., Duhig, S. J., & Shield, A. J. (2015). Eccentric hamstring strength and hamstring injury risk in Australian footballers. *Medicine & Science in Sports & Exercise, 47*(4), 857–865. https://doi.org/10.1249/MSS.0000000000000465

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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THIGH COMPARTMENT SYNDROME: SEVERE SWELLING AFTER IMPACT OR EXERTION

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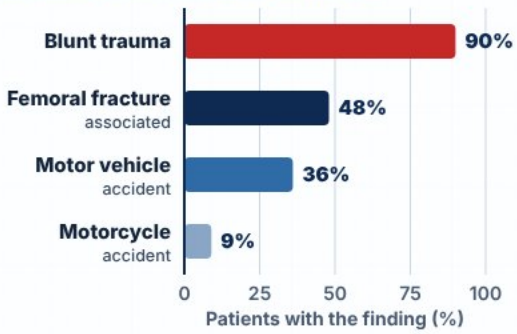
A · RESTING SUPINE, SIDE



A rare but time-critical emergency

- Lying on her back, one knee bent and a hand resting on the front of the thigh. In compartment syndrome, pressure inside a closed muscle compartment rises until blood flow is compromised.
- It is rare, affecting fewer than 0.3% of trauma patients, and is treated by urgent surgical decompression (fasciotomy), not by rest at home.

Most cases follow heavy impact



Systematic review of 9 retrospective series, 89 patients with thigh compartment syndrome. Ojike et al. (2010).

Key point: cases after squats, running or cycling are rare but reported, so the warning signs also apply to athletes.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). No landmark angles: pose detection is unreliable for lying poses. Educational, not diagnostic.

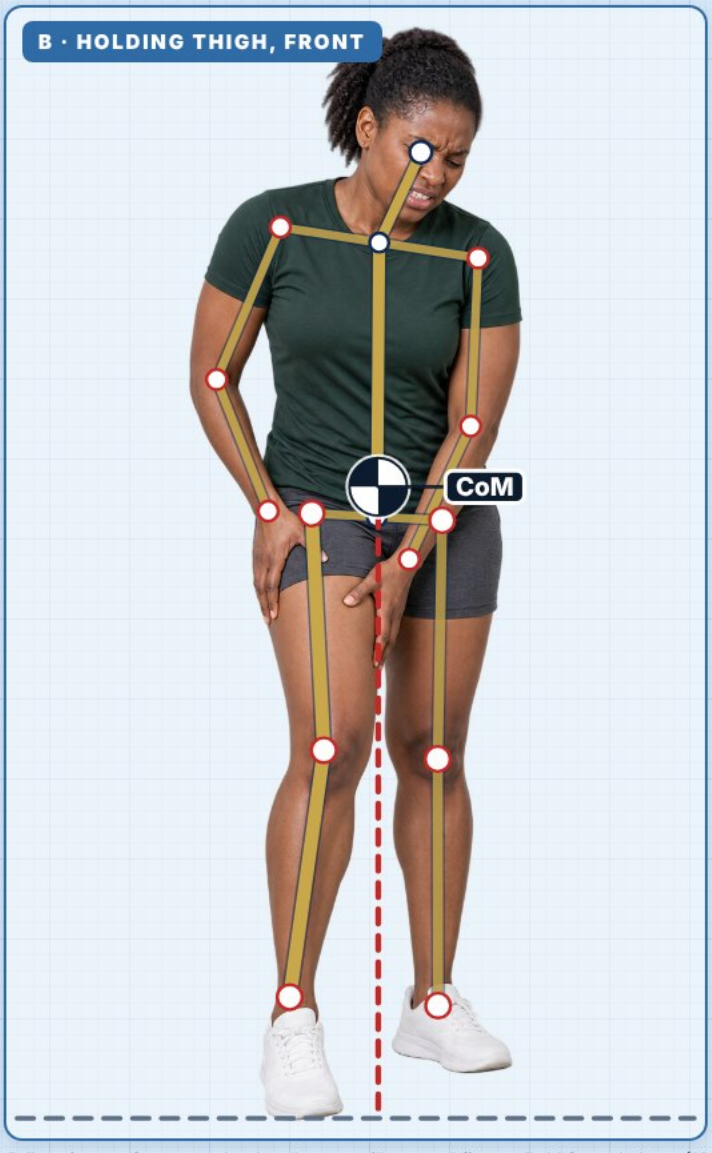
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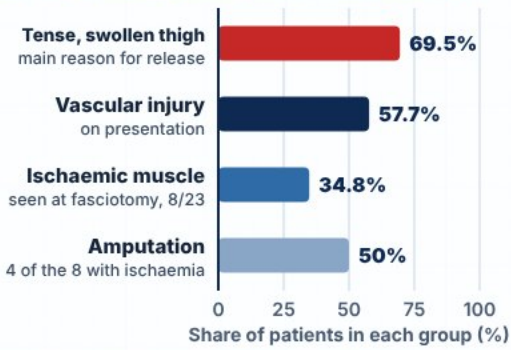
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A tense, swollen thigh is the main sign

- Standing and wincing, both hands pressed on the front of the right thigh. Pain that keeps escalating, with a thigh that feels tense, is what should raise concern.
- In 26 thigh compartment syndromes, a tense, swollen thigh was the most consistent reason for surgery; a third of patients already had ischaemic muscle.

What surgeons found, and what followed



23 patients, 26 thighs, two Level 1 trauma centres; mean age 35.4 years. Kanlic et al. (2010).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Skeleton and CoM only in this front view. Educational, not diagnostic.

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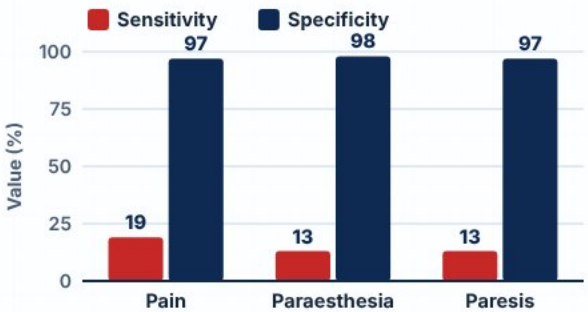
C · KNEE HELD STRAIGHT, SIDE



Unable to bend the knee

- Seated on a bench, the right knee held almost straight (**7°** of flexion): bending it would stretch the front-thigh muscles. Pain on passive stretch was one basis for surgery in a thigh series.
- Classic signs caught only 13–19% of lower-leg cases, so their absence does not rule the condition out.

Classic signs miss most cases



Lower-leg (not thigh) data; systematic review values as summarised in a Best Evidence Topic. BestBETs (n.d.).

Myth: "It's just a bad dead leg; ice it and wait for the numbness to pass." Waiting for numbness or weakness means waiting too long.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Knee angle from pose landmarks in the side view (0° = straight). Educational, not diagnostic.

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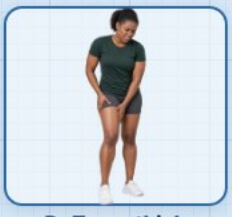
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A · Resting
Rest will not fix it

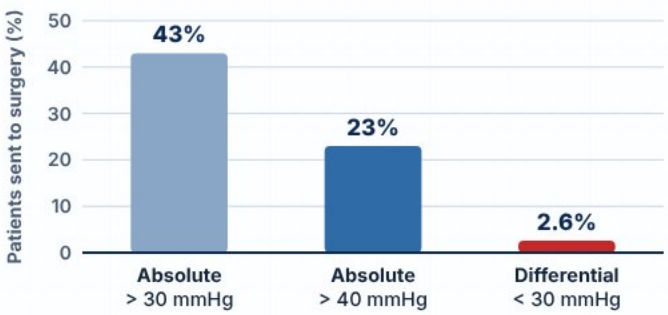


B · Tense thigh
Main warning sign



C · Knee held straight
Knee 7°

Differential pressure avoids over-treatment



Lower-leg data: 116 tibial fractures, 24 h pressure monitoring; differential = diastolic minus compartment pressure; no missed cases. McQueen and Court-Brown (1996).

Decision pathway

1. **ACT FAST**
   Escalating pain and a tense thigh after a blow, crush or fracture need emergency care now.
2. **DON'T WAIT**
   Numbness and weakness are late and unreliable signs; do not wait for them to appear.
3. **REHAB LATER**
   Treatment is surgical decompression; exercise-based rehabilitation starts only after surgery.

NOT RECOMMENDED

Treating a tense, swollen thigh as a simple bruise; icing and waiting at home; massaging or stretching it.

SEEK ASSESSMENT IF

Escalating thigh pain after impact, pain on bending the knee, a tense swollen thigh, a bleeding disorder or anticoagulant use, or dark urine after extreme exertion.

REFERENCES (APA 7)

BestBETs. (n.d.). Diagnostic utility of clinical signs and symptoms in the diagnosis of compartment syndrome of the lower limb. https://bestbets.org/bets/bet.php?id=1252

Chiang, A. S., & Tejwani, N. C. (2007). Acute compartment syndrome of the thigh: Diagnosis and management. *Joint Diseases and Related Surgery, 18*(2), 72–77.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Kanlic, E. M., Pinski, S. E., Verwiebe, E. G., Saller, J., & Smith, W. R. (2010). Acute morbidity and complications of thigh compartment syndrome: A report of 26 cases. *Patient Safety in Surgery, 4*, 13. https://doi.org/10.1186/1754-9493-4-13

Khan, S. K., Thati, S., & Gozzard, C. (2011). Spontaneous thigh compartment syndrome. *Western Journal of Emergency Medicine, 12*(1), 134–138.

McQueen, M. M., & Court-Brown, C. M. (1996). Compartment monitoring in tibial fractures: The pressure threshold for decompression. The Journal of Bone and Joint Surgery, British Volume, 78-B(1), 99–104. https://doi.org/10.1302/0301-620X.78B1.0780099

McQueen, M. M., Gaston, P., & Court-Brown, C. M. (2000). Acute compartment syndrome: Who is at risk? The Journal of Bone and Joint Surgery, British Volume, 82-B(2), 200–203. https://doi.org/10.1302/0301-620X.82B2.0820200

Ojike, N. I., Roberts, C. S., & Giannoudis, P. V. (2010). Compartment syndrome of the thigh: A systematic review. *Injury, 41*(2), 133–136.

Scalco, R. S., Snoeck, M., Quinlivan, R., Treves, S., Laforét, P., Jungbluth, H., & Voermans, N. C. (2016). Exertional rhabdomyolysis: Physiological response or manifestation of an underlying myopathy? *BMJ Open Sport & Exercise Medicine, 2*(1), e000151. https://doi.org/10.1136/bmjsem-2016-000151

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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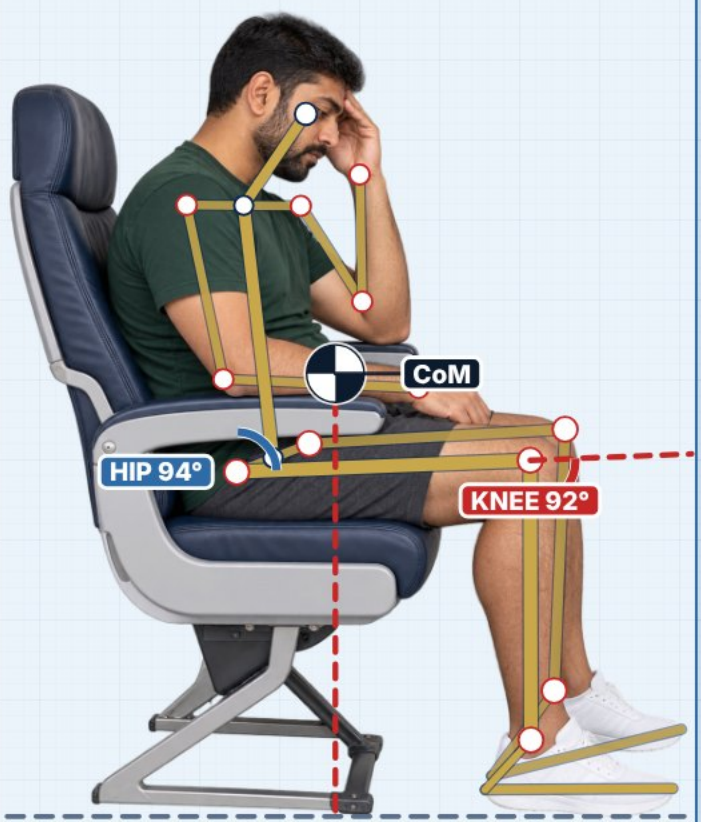
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DEEP VEIN THROMBOSIS: CALF OR THIGH PAIN THAT IS NOT A MUSCLE INJURY

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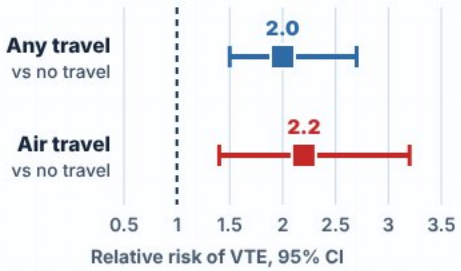
A · LONG-HAUL SITTING, SIDE



Long, still sitting slows the veins

- Slumped in an airline-style seat, hip flexed **94°** and knee **92°**, legs still. Travel of four hours or more about doubles the risk of a clot in a deep vein.
- Each extra 2 h of travel was associated with about 18% higher risk. The absolute risk stays low, about 1 in 6000 for more than four hours seated and immobile.

Travel about doubles the risk



Meta-analysis of observational studies; VTE = venous thromboembolism. Chandra et al. (2009).

Key point: the risk stays raised for about four weeks after the journey, so new leg pain in that window deserves attention.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Hip and knee angles from pose landmarks in the side view. Educational, not diagnostic.

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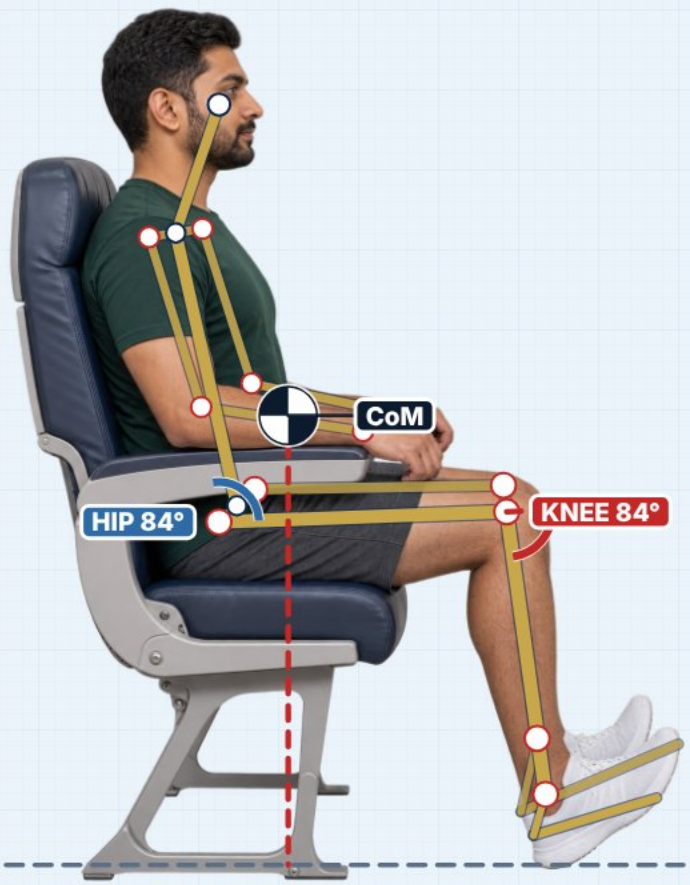
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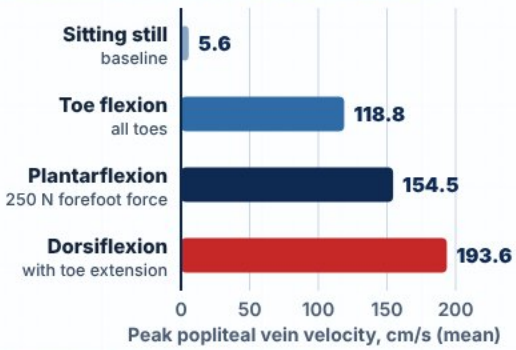
B · SEATED ANKLE PUMP, SIDE



The calf pump moves the blood

- Upright in the same seat, knee **84°**, pulling the toes and foot up: contracting the calf and shin muscles squeezes the deep veins and pushes blood back towards the heart.
- Forceful dorsiflexion raised peak popliteal vein velocity more than 30-fold over sitting still. This shows the pump at work; it does not by itself prove fewer clots.

Forceful ankle work speeds venous flow



20 healthy seated adults; Doppler ultrasound of the popliteal vein. Kropp et al. (2018).

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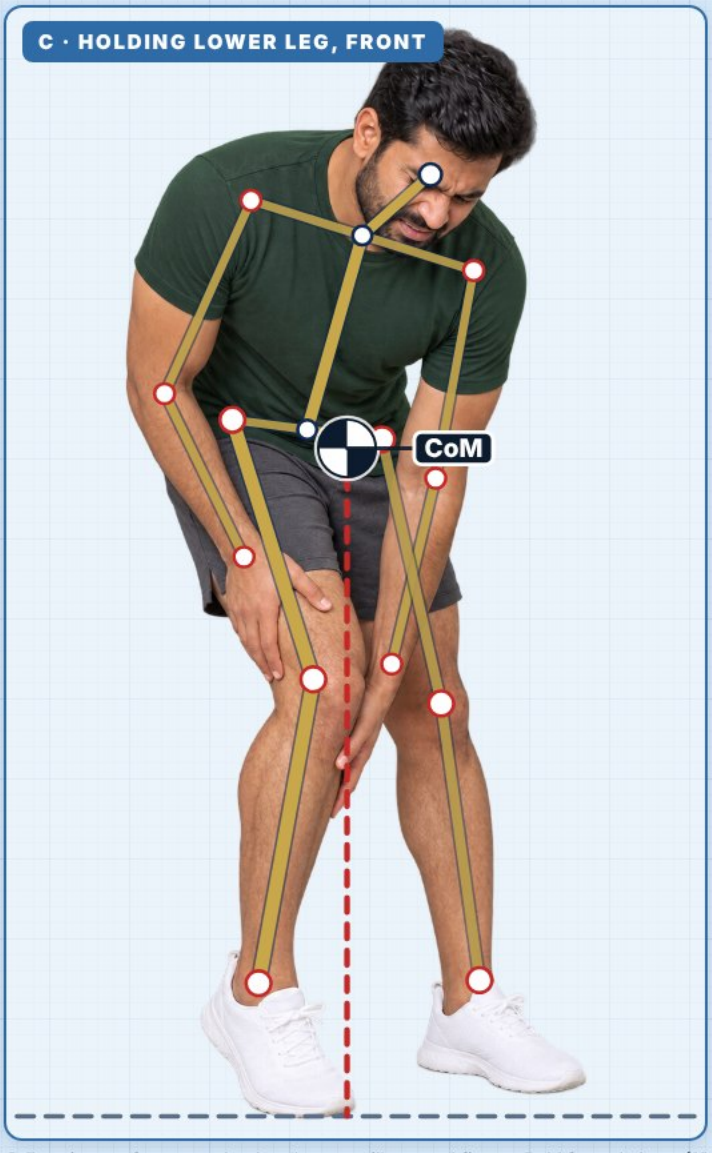
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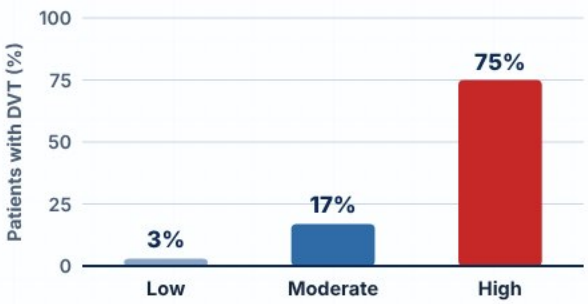
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Pain that is not a strain

- Standing bent forward, grimacing, both hands gripping around the right knee and upper calf. A DVT can cause pain, swelling and warmth here that is easily mistaken for a muscle injury.
- Clinicians use a probability score first: it sorts people into groups with very different likelihoods, which decides the next test.

The score sorts the likelihood



593 outpatients with suspected DVT, by pretest probability; 16% had DVT overall. Wells et al. (1997).

Myth: "A painful, swollen calf after a long flight is just cramp." A one-sided swollen, painful leg needs testing, not massage or stretching.

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A · Long sitting
Risk about doubles

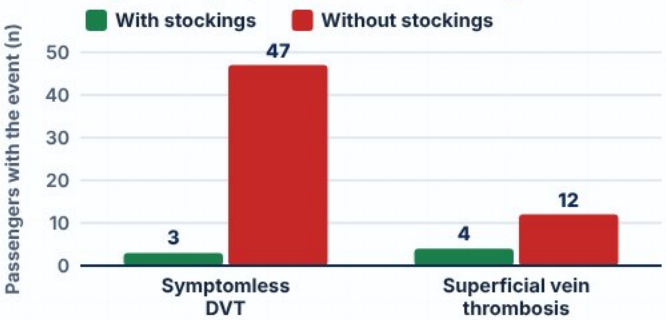


B · Ankle pump
Venous flow up



C · Leg pain
Needs testing

Stockings cut symptomless clots on flights



Cochrane review, flights > 5 h; symptomless DVT 9 trials, 2637 people, OR 0.10 (95% CI 0.04–0.25), high certainty. Clarke et al. (2021).

Decision pathway

1. **MOVE**
   On long journeys, break up sitting and use forceful ankle and toe pumps to drive venous return.
2. **PROTECT**
   On flights over 5 hours, compression stockings reduced symptomless DVT in randomised trials.
3. **GET TESTED**
   Suspected DVT is assessed with a probability score, then a D-dimer test and/or ultrasound.

NOT RECOMMENDED

Massaging, stretching or loading a swollen, painful calf or thigh before a DVT has been ruled out.

SEEK ASSESSMENT IF

One-sided calf or thigh pain and swelling, especially within four weeks of a journey of 4 h or more. Sudden breathlessness or chest pain: call emergency services.

REFERENCES (APA 7)

Chandra, D., Parisini, E., & Mozaffarian, D. (2009). Meta-analysis: Travel and risk for venous thromboembolism. *Annals of Internal Medicine, 151*(3), 180–190.

Clarke, M. J., Broderick, C., Hopewell, S., Juszczak, E., & Eisinga, A. (2021). Compression stockings for preventing deep vein thrombosis in airline passengers. *Cochrane Database of Systematic Reviews, 2021*(4), CD004002. https://doi.org/10.1002/14651858.CD004002.pub4

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Kropp, A. T., Meiss, A. L., Guthoff, A. E., Vettorazzi, E., Guth, S., & Bamberger, C. M. (2018). The efficacy of forceful ankle and toe exercises to increase venous return: A comprehensive Doppler ultrasound study. *Phlebology, 33*(5), 330–337. https://doi.org/10.1177/0268355517706042

National Institute for Health and Care Excellence. (2020). NICE guideline NG158: Recommendations. https://www.nice.org.uk/guidance/ng158/chapter/Recommendations

Wells, P., Anderson, D. R., Bormanis, J., Guy, F., Mitchell, M., Gray, L., Clement, C., Robinson, K. S., & Lewandowski, B. (1997). Value of assessment of pretest probability of deep-vein thrombosis in clinical management. *The Lancet, 350*(9094), 1795–1798.

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

World Health Organization. (2007, June 29). Study results released on travel and blood clots [News release]. https://www.who.int/news/item/29-06-2007-study-results-released-on-travel-and-blood-clots

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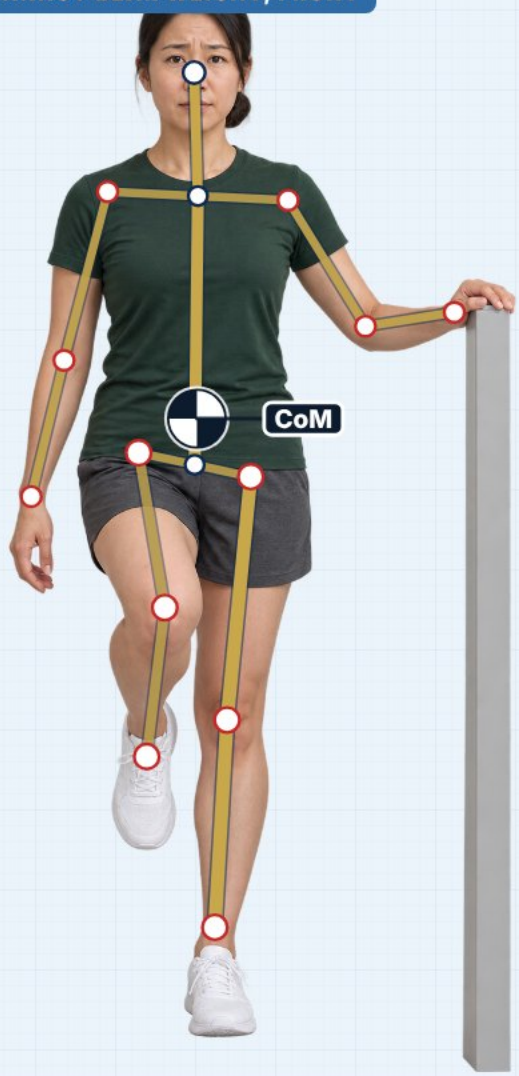
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THIGH RED FLAGS: WHEN THIGH PAIN NEEDS URGENT MEDICAL CARE

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A · CANNOT BEAR WEIGHT, FRONT



Cannot put weight through the leg

- Standing on the left leg only, right foot held off the floor and one hand on a post for balance. Being unable to bear weight is a red flag, not a reason to rest and wait.
- In runners, deep groin or thigh pain that builds with each run can be a femoral neck stress fracture; once it displaces, far fewer return to running.

Catch a stress fracture early



Systematic review, 48 runners with femoral neck stress fractures; % calculated from published counts. Neubauer et al. (2016).

Key point: unable to bear weight with a fever needs urgent medical assessment for infection of the hip.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Skeleton and CoM only in this front view; no angles quoted. Educational, not diagnostic.

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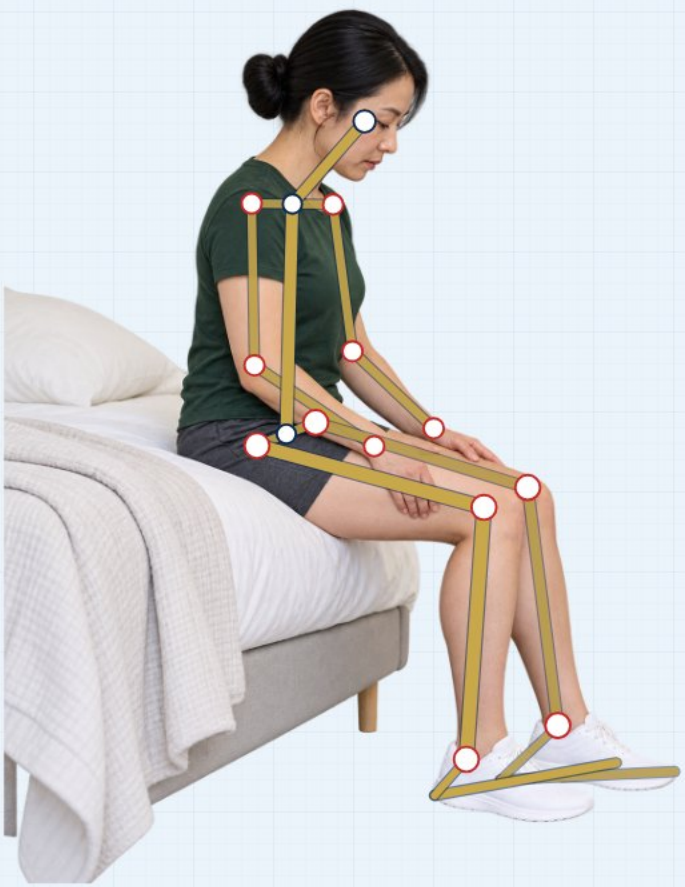
BIOMECHANICS IS A FORCE-GOVERNED DECISION SYSTEM – NOT A POSTURE MODEL.

INTEGRATING PERFORMANCE & REHABILITATION HEALTHCARE PATHWAYS.

THIGH RED FLAGS: WHEN THIGH PAIN NEEDS URGENT MEDICAL CARE

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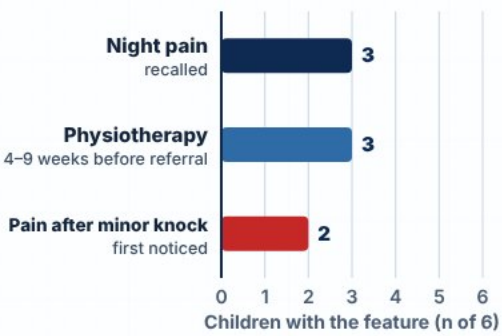
B · SITTING ON BED, SIDE



Pain that wakes you at night

- Sitting on the edge of the bed, looking down, hands resting on the right thigh. Thigh or knee pain at night or at rest, without a clear injury, is a reason to see a doctor.
- In six children with bone sarcoma, treatment began a mean of 114 days after the first symptoms, 81% of that time in primary care.

Warning signs before diagnosis



Children's data: 6 children with osteosarcoma or Ewing sarcoma; small case series, illustrative only. Dhinsa et al. (2020).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Skeleton only; no angles quoted for this seated pose. Educational, not diagnostic.

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C · AFTER A FALL, FRONT



After a fall: a normal X-ray is not the end

- Sitting on the floor after a fall, grimacing, both hands holding the right thigh just above the knee. Thigh or hip pain and being unable to stand after a fall need assessment.
- In older adults with a suspected hidden hip fracture, 39.6% (71 of 179) had one confirmed; MRI is advised if the X-ray is normal but suspicion persists.

Further imaging takes days



Older adults with suspected occult hip fracture; CT missed 3 of 24 fractures seen on MRI. Secondary summary: BestBETs (n.d.).

Myth: "If the X-ray is normal, it can't be broken." Hidden fractures are confirmed in a real share of people tested further.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Skeleton only; no angles quoted for this floor-sitting pose. Educational, not diagnostic.

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A · No weight bearing
Red flag

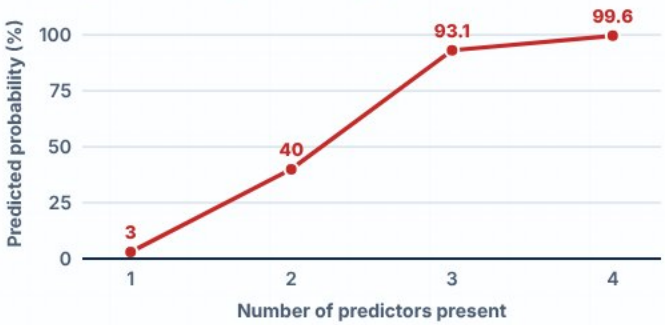


B · Night pain
Refer for imaging



C · After a fall
X-ray may miss it

Fever plus no weight bearing: act fast



Children's data: 282 children with an irritable hip; predictors: fever, non-weight-bearing, ESR ≥ 40 mm/h, WCC > 12,000/mm³; < 0.2% with none. Kocher et al. (1999).

Decision pathway

1. **STOP**
   Do not stretch, massage or train through thigh pain that shows any red flag.
2. **GET CHECKED**
   Seek prompt medical assessment; imaging or blood tests decide the cause, not exercise.
3. **THEN REHAB**
   Once serious causes are excluded, rehabilitation follows the specific diagnosis.

NOT RECOMMENDED

Treating persistent, unexplained thigh pain as "just a strain" for weeks without a medical diagnosis.

SEEK ASSESSMENT IF

Fever with inability to bear weight; unable to stand after a fall; night pain; pain that builds with each run; dark urine after extreme exercise.

REFERENCES (APA 7)

BestBETs. (n.d.). CT vs. MRI in the occult hip fracture. https://bestbets.org/bets/bet.php?id=2979

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Dhinsa, T. J., Mahon, P., & Strahlendorf, C. (2020). Sometimes we need to think of zebras: An observational study on delays in the identification of bone tumors in children. *BC Medical Journal, 62*(4), 130–133.

Kocher, M. S., Zurakowski, D., & Kasser, J. R. (1999). Differentiating between septic arthritis and transient synovitis of the hip in children: An evidence-based clinical prediction algorithm. *The Journal of Bone and Joint Surgery, American Volume, 81*(12), 1662–1670.

Neubauer, T., Brand, J., Lidder, S., & Krawany, M. (2016). Stress fractures of the femoral neck in runners: A review. *Research in Sports Medicine, 24*(3), 283–297. https://doi.org/10.1080/15438627.2016.1191489

Scalco, R. S., Snoeck, M., Quinlivan, R., Treves, S., Laforét, P., Jungbluth, H., & Voermans, N. C. (2016). Exertional rhabdomyolysis: Physiological response or manifestation of an underlying myopathy? *BMJ Open Sport & Exercise Medicine, 2*(1), e000151. https://doi.org/10.1136/bmjsem-2016-000151

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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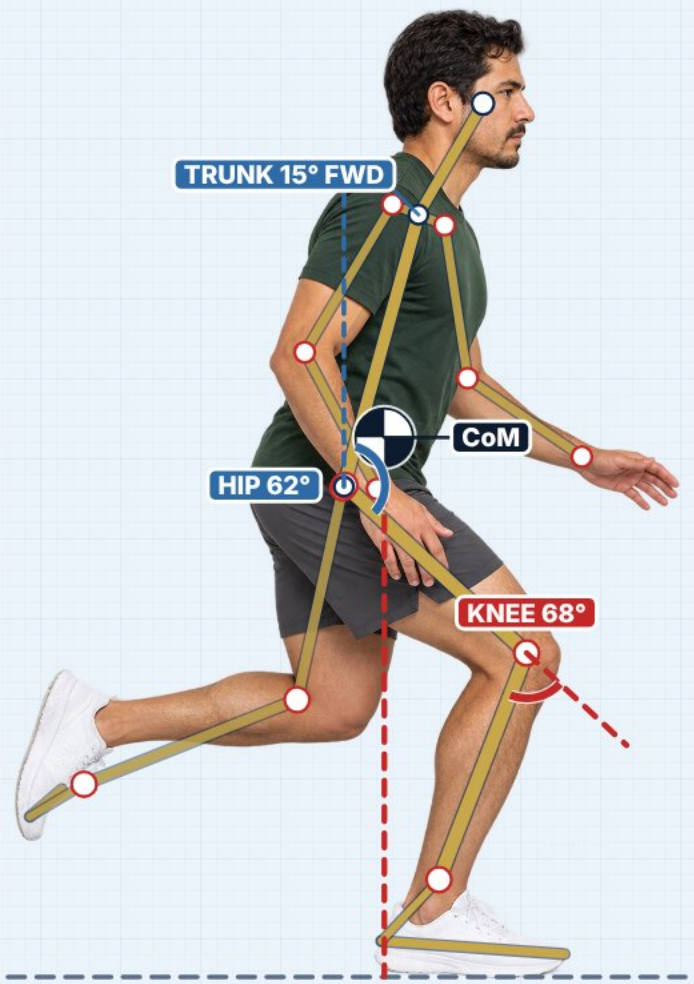
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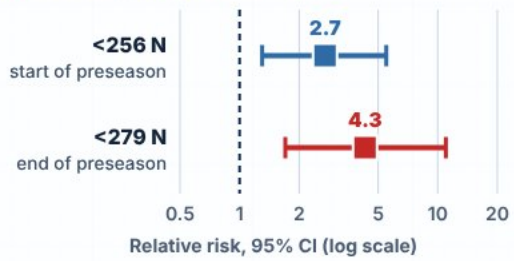
A · SINGLE-LEG HOP, SIDE



Hop landing: strength on one leg

- Landing a long hop on the right leg, balanced, with the hip flexed **62°**, knee **68°** and trunk **15°** forward: the limb must absorb the landing alone.
- Hops compare sides, but in elite footballers low absolute eccentric strength raised risk, while a left–right imbalance above 10% did not.

Eccentric strength thresholds



210 elite Australian footballers, 28 new hamstring injuries; Nordic-device knee-flexor force. Opar et al. (2015).

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk, hip and knee angles from pose landmarks in the side view; landing poses are approximate. Educational, not diagnostic.

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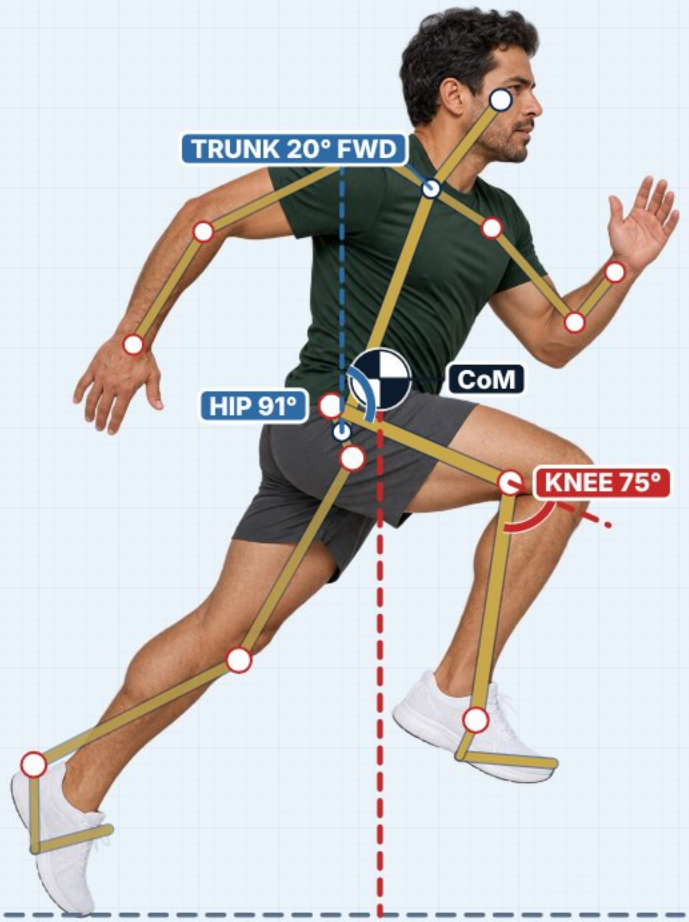
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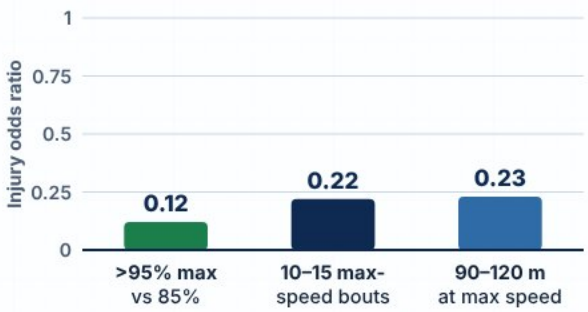
B · FULL-SPEED SPRINT, SIDE



Full speed before full return

- Confident full-speed sprinting, front hip flexed **91°** and knee **75°**, trunk **20°** forward: the hamstrings face their highest demand at this speed.
- Reaching more than 95% of maximal speed in training was associated with far lower injury odds (OR 0.12) than reaching only 85%.

Top-speed exposure and injury odds



37 elite Gaelic footballers, one season, all injury types; the last two with high chronic load. Malone et al. (2017).

Key point: avoiding top speed is not protective; reach and repeat near-maximal speed in training before match return.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Trunk, hip and knee angles from pose landmarks in the side view; sprint poses are approximate. Educational, not diagnostic.

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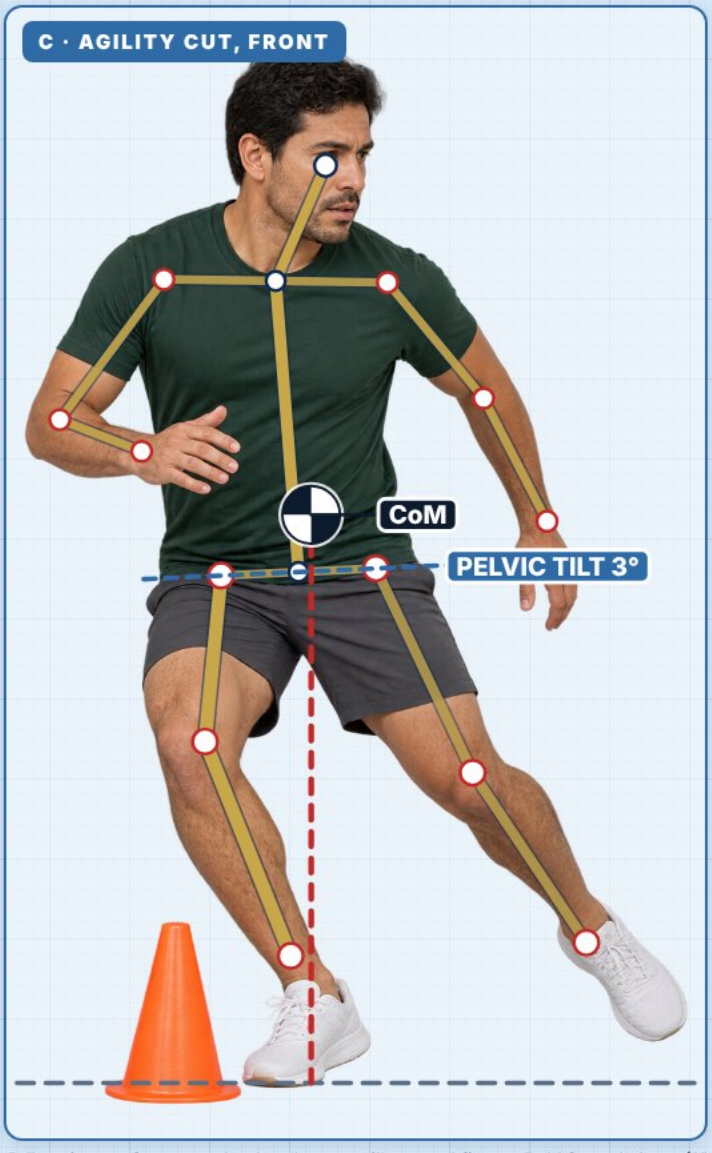
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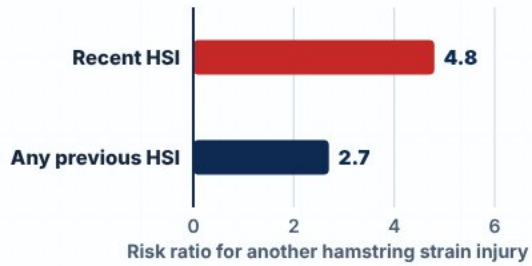
C · AGILITY CUT, FRONT



Cutting: confidence under change

- Planting the outside foot beside a cone and turning the body away, with the pelvis **3°** off level: speed, strength and control must combine in one movement.
- No single set of return-to-play criteria has been validated, so guidance favours several measures together, including running and sprinting tests.

A recent injury is the biggest risk



78 studies, 71,324 athletes; HSI = hamstring strain injury. Green et al. (2020).

Myth: "If it no longer hurts and I can sprint once, I am ready." Readiness is a combination of tests, not one moment.

2-D estimates from pose landmarks on an illustrated figure; CoM from de Leva (1996) segment parameters; cm for a 1.70 m adult (Winter, 2009). Pelvis line between hip landmarks in the front view. Educational, not diagnostic.

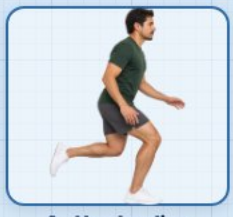
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A · Hop landing
Knee 68°

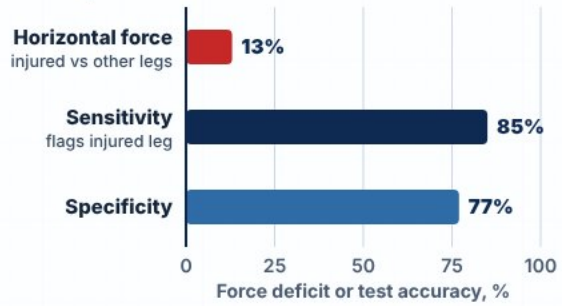


B · Full speed
Hip 91°



C · Agility cut
Combined control

Repeated sprints reveal hidden deficits



20 footballers with a previous hamstring injury, 20 without; 13% lower force ($p = 0.001$), AUC 0.846. Lord et al. (2019).

Decision pathway

1. **STRENGTH**
   Measure knee-flexor strength with a dynamometer; low eccentric force carried 2.7–4.3× risk.
2. **SPEED**
   Test repeated sprints and confirm near-maximal speed in training before match return.
3. **PROGRESS**
   Use injury history in the plan and keep the Nordic exercise going after return.

NOT RECOMMENDED

Returning after one pain-free sprint; skipping eccentric rehabilitation.

SEEK ASSESSMENT IF

Pain returns during sprinting, a new sudden sharp pain or loss of function, or weakness, bruising or numbness near the sitting bone.

REFERENCES (APA 7)

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223–1230. https://doi.org/10.1016/0021-9290(95)00178-6

Green, B., Bourne, M. N., van Dyk, N., & Pizzari, T. (2020). Recalibrating the risk of hamstring strain injury (HSI): A 2020 systematic review and meta-analysis of risk factors for index and recurrent hamstring strain injury in sport. *British Journal of Sports Medicine, 54*(18), 1081–1088. https://doi.org/10.1136/bjsports-2019-100983

Lord, C., Blazevich, A. J., Drinkwater, E. J., & Ma'ayah, F. (2019). Greater loss of horizontal force after a repeated-sprint test in footballers with a previous hamstring injury. *Journal of Science and Medicine in Sport, 22*(1), 16–21. https://doi.org/10.1016/j.jsams.2018.06.008

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. (2017). High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *Journal of Science and Medicine in Sport, 20*, 250–254. https://doi.org/10.1016/j.jsams.2016.08.005

Martin, R. L., Cibulka, M. T., Bolgla, L. A., Koc, T. A., Jr., Loudon, J. K., Manske, R. C., Weiss, L., Christoforetti, J. J., & Heiderscheit, B. C. (2022). Hamstring strain injury in athletes: Clinical practice guidelines. *Journal of Orthopaedic & Sports Physical Therapy, 52*(3), CPG1–CPG44. https://doi.org/10.2519/jospt.2022.0301

Opar, D. A., Williams, M. D., Timmins, R. G., Hickey, J., Duhig, S. J., & Shield, A. J. (2015). Eccentric hamstring strength and hamstring injury risk in Australian footballers. *Medicine & Science in Sports & Exercise, 47*(4), 857–865. https://doi.org/10.1249/MSS.0000000000000465

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Wiley. https://doi.org/10.1002/9780470549148

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