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The Relationship Between Menstrual Cycle Characteristics and Neuromuscular Control During Lower-Limb Rehabilitation

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Abstract

Background: Women sustain non-contact anterior cruciate ligament (ACL) injuries at two to eight times the rate of men, and they make up a growing share of patients in lower-limb rehabilitation. Ovarian hormones change ligament compliance, corticospinal excitability, and muscle fatigability across the menstrual cycle. Most rehabilitation protocols still ignore this.

Aim: To synthesise the evidence linking menstrual cycle characteristics (phase, cycle regularity, symptom burden and hormonal contraceptive use) to neuromuscular control of the lower limb, and to translate it into a practical, phase-informed rehabilitation framework.

Methods: A narrative evidence synthesis of systematic reviews, meta-analyses and mechanistic studies in eumenorrheic women and hormonal contraceptive users, with emphasis on knee laxity, strength, motor unit behaviour, fatigability, proprioception and landing biomechanics.

Results: At group level, cycle phase has a trivial effect on maximal performance (pooled effect size -0.06 in the early follicular phase across 78 studies). Effects on the control side are larger and more consistent: anterior knee laxity rises around ovulation, knee-extensor fatigability and corticospinal excitability shift between phases, and low-threshold motor unit firing changes without any change in force output. Individual variation is large, so a single phase-based rule for all women is not supported.

Conclusion: Menstrual cycle characteristics should be tracked and used to individualise lower-limb rehabilitation, not to standardise it. We propose a five-step clinical framework: screen, track, monitor, adjust and re-test. It targets neuromuscular control rather than load alone.

Keywords: Menstrual cycle; Neuromuscular control; Anterior cruciate ligament; Knee laxity; Rehabilitation; Oestrogen; Progesterone; Hormonal contraception; Personalised physical therapy

INTRODUCTION

Lower-limb rehabilitation in women is usually planned as if female physiology were constant from week to week. It is not. Over a typical 21–35-day cycle, oestradiol and progesterone rise and fall several-fold, and both hormones act on ligament, muscle and the central nervous system. Those are the three tissues that determine neuromuscular control of the knee.

The clinical stakes are high. Female athletes in high-risk sports such as soccer, basketball, and volleyball tear the ACL at four to six times the rate of male athletes, and most of these injuries happen without contact (Hewett *et al.*, 2005). Non-

contact ACL injury is fundamentally a failure of neuromuscular control: the knee collapses into valgus during landing or cutting. In a prospective cohort of 205 female athletes, those who later ruptured the ACL landed with 8° more knee abduction, and knee abduction moment predicted injury with 78% sensitivity and 73% specificity (Hewett *et al.*, 2005).

Rehabilitation after ACL reconstruction, ankle sprain, patellofemoral pain, or meniscal surgery aims to restore exactly this control. Yet return-to-sport testing, load progression, and re-injury screening rarely record where a patient is in her cycle. A hop test done on day 2 and repeated

on day 14 may measure the hormone environment as much as the intervention.

Three practical problems follow:

1. *Measurement noise*: Unrecorded cycle phase adds variance to laxity, strength, and landing tests, so real progress or real deficits can be hidden.
2. *Mistimed loading*: High-demand plyometric and cutting drills may be scheduled when passive knee restraint is lowest, without extra active protection.
3. *Symptom-driven drop-out*: Menstrual symptoms are common in active women and reduce training availability. Unaddressed, they lower adherence to rehabilitation.

Russian-language clinical literature has argued for some time that physical therapy should be personalised to menstrual cycle phase (Васильцова, 2022). The international evidence base has since grown, but it is fragmented across sports science, orthopaedics and neurophysiology. This article brings those strands together. It asks one question: which menstrual cycle characteristics change lower-limb neuromuscular control enough to matter in rehabilitation, and what should clinicians do about it?

PHYSIOLOGICAL BASIS: HOW OVARIAN HORMONES REACH NEUROMUSCULAR CONTROL

Oestrogen and progesterone affect neuromuscular control through three routes: passive joint restraint, the central nervous system, and the muscle itself. Each route has a different time course, which is why single-day measurements are so variable.

The Cycle in Four Working Phases

Research now uses verified phases rather than calendar guesses (Elliott-Sale *et al.*, 2021). For clinical use, four phases are enough (Table 1).

Passive Restraint: Ligament and Tendon

The human ACL carries receptors for oestrogen, progesterone, and relaxin. Oestrogen reduces fibroblast proliferation and collagen synthesis in ligament tissue, which can lower stiffness (Chidi-Ogbolu and Baar, 2019). Anterior knee laxity therefore rises when oestrogen peaks. Shultz *et al.* (2004) showed that laxity changes follow hormone changes with a lag of several days, so laxity on a given day reflects the hormones of the previous days.

A more lax knee is not automatically injured. It shifts the burden of stability onto active control: the hamstrings, quadriceps and hip musculature must respond faster and harder to hold the tibia.

Central Drive: Brain and Spinal Cord

Oestradiol is broadly neuro-excitatory, partly by enhancing glutamatergic transmission. Progesterone and its metabolite allopregnanolone are inhibitory through GABA-A receptors. Using transcranial magnetic stimulation, Smith *et al.* (2002) found reduced intracortical inhibition in the late follicular phase and increased inhibition in the luteal phase. Ansdell *et al.* (2019) extended this to the knee extensors, showing that corticospinal and intracortical responses, voluntary activation, and fatigability all varied between days 2, 14, and 21.

For rehabilitation, this means the nervous system’s readiness to recruit muscle, and to resist fatigue, is not fixed across the month.

The Muscle: Motor Units and Fatigue

Oestrogen has anabolic and membrane-stabilising effects on skeletal muscle. Progesterone may be mildly catabolic. Piasecki *et al.* (2023) recorded vastus lateralis motor units with intramuscular electromyography across three phases. Low-threshold motor unit firing rates changed between phases, yet strength, force steadiness, power, and balance did not. Control strategy changed even though output looked identical.

That finding is the core argument of this article: standard strength tests can miss cycle-related changes in how force is produced.

METHODS

This is a narrative evidence synthesis designed to answer a clinical question, not a new meta-analysis.

Sources

PubMed, Google Scholar, PubMed Central, and the Russian scientific databases eLIBRARY and APNI were searched for literature published up to September 2026.

Search Terms

Combinations of menstrual cycle, oestrogen/estrogen, progesterone, and hormonal contraceptive with neuromuscular control, knee laxity, ACL, proprioception,

Table 1: Working phases of the menstrual cycle and their neuromuscular relevance.

Phase (typical days, 28-day cycle)	Oestradiol	Progesterone	Main neuromuscular relevance
Early follicular (days 1–5, menses)	Low	Low	Pain, cramps and fatigue peak; hormonal profile closest to male; most stable baseline for testing
Late follicular (days 6–12)	Rising to peak	Low	Neuro-excitatory oestrogen effect; corticospinal excitability tends to rise
Ovulatory (days 13–15)	Peak, then sharp fall	Starting to rise	Anterior knee laxity highest; luteinising hormone surge
Mid-luteal (days 19–23)	Moderate second peak	Peak	Progesterone-mediated inhibition; higher core temperature; altered fatigability

Note: Day ranges are illustrative. Cycle length varies between 21 and 35 days in healthy women, and the follicular phase accounts for most of that variation. Phase should be confirmed with ovulation tests or hormone measurement where decisions depend on it.

landing biomechanics, corticospinal excitability, fatigability, motor unit, and rehabilitation. Russian terms included фазы менструального цикла, физическая терапия and реабилитация.

Selection Priorities

1. Systematic reviews and meta-analyses, for the size of group-level effects.
2. Prospective cohort studies of injury, for clinical relevance.
3. Mechanistic studies with hormonally verified phases (TMS, intramuscular EMG, laxity arthrometry), for physiological plausibility.
4. Applied and clinical-practice literature on phase-based training and rehabilitation, including Russian-language work.

Characteristics Examined

Cycle phase; cycle regularity (eumenorrhoea versus oligo- or amenorrhoea); menstrual symptom burden; and hormonal contraceptive use.

Appraisal

Studies were weighted by whether phase was verified hormonally, by sample size, and by whether the outcome reflected control (timing, activation, kinematics) or only capacity (maximal force).

RESULTS: WHAT THE EVIDENCE SHOWS

The clearest pattern is a split between capacity and control. Maximal force barely moves with the cycle. Laxity, proprioception, coordination, motor unit behaviour, and fatigability do move, and these are the variables that protect the knee.

Key Studies at a Glance

Table 2 provides a study-by-study summary of the evidence discussed in this section.

Passive Knee Laxity

Anterior knee laxity is the most consistent cycle-dependent variable. Herzberg *et al.* (2017) pooled six laxity studies and found significantly greater laxity in the ovulatory phase than in the follicular phase. This is reflected in Table 2. The same review noted that the overall quality of evidence was very low, mainly because phases were often not verified.

For rehabilitation after ACL reconstruction, the clinically important question is whether graft-site and contralateral laxity change across the cycle. Data here are scarce, which makes routine laxity re-testing in the same phase a sensible precaution.

Strength and Power

At group level, strength is almost unaffected. McNulty *et al.* (2020) found a trivial early follicular reduction, and Colenso-Semple *et al.* (2023) found no consistent effect on strength or

Table 2: Summary of key studies on menstrual cycle characteristics and lower-limb neuromuscular outcomes.

Study	Design and sample	Outcome	Main finding
McNulty <i>et al.</i> (2020)	Meta-analysis; 78 studies, 1,193 eumenorrhoeic women	Strength and endurance performance	Trivial reduction in early follicular phase (ES -0.06; 95% CrI -0.16 to 0.04); individualised approach recommended
Colenso-Semple <i>et al.</i> (2023)	Umbrella review of meta-analyses and systematic reviews	Acute strength; resistance-training adaptation	No consistent phase effect on strength or adaptation
Kissow <i>et al.</i> (2022)	Critical review of phase-based resistance training	Strength and muscle mass	Follicular-based loading possibly superior; evidence limited and inconsistent
Herzberg <i>et al.</i> (2017)	Systematic review and meta-analysis; 21 studies, 68,758 participants	ACL injury and knee laxity	Laxity significantly higher at ovulation than in follicular phase; luteal phase least associated with ACL injury in 4 of 5 studies
Hewett <i>et al.</i> (2005)	Prospective cohort; 205 female athletes	Landing kinematics and kinetics	Injured athletes landed with 8° more knee abduction; abduction moment 78% sensitive, 73% specific for ACL injury
Fridén <i>et al.</i> (2006)	Prospective; 25 women, hormonally verified phases over 3 cycles	Knee kinaesthesia; square hop test	Kinaesthesia impaired premenstrually; hop coordination best at ovulation
Abt <i>et al.</i> (2007)	Repeated measures across menses, ovulation and mid-luteal phase	Balance, coordination, strength, landing biomechanics	No significant phase differences
Ansdell <i>et al.</i> (2019)	TMS and nerve stimulation on days 2, 14 and 21	Knee-extensor neural function and fatigability	Corticospinal function and fatigability varied by phase; ~36% longer time to task failure in mid-luteal vs early follicular phase
Piasecki <i>et al.</i> (2023)	Intramuscular EMG; 9 women, 3 verified phases	Vastus lateralis motor unit firing	Low-threshold motor unit firing changed; strength, steadiness, power and balance did not
Bruinvels <i>et al.</i> (2021)	Survey; 6,812 exercising women	Menstrual symptoms and training availability	Mood change/anxiety 90.6%, fatigue 86.2%, cramps 84.2%; symptoms reduced exercise participation

Note: ES = effect size; CrI = credible interval; TMS = transcranial magnetic stimulation; EMG = electromyography.

training adaptation. Rehabilitation therefore does not need to drop load across the board during particular phases. The authors of both reviews recommend individual tracking instead.

Proprioception, Coordination and Balance

Here the evidence is mixed but clinically meaningful. Fridén *et al.* (2006) verified phases hormonally over three consecutive cycles. Knee kinaesthesia was worse premenstrually, while square-hop coordination was best at ovulation. Abt *et al.* (2007), using a broader test battery, found no phase differences.

The conflict likely reflects test sensitivity. Simple balance and strength tasks may be too coarse, while specific kinaesthetic and hop-coordination tests detect change.

Central Drive and Fatigability

Ansdeell *et al.* (2019) provide the strongest neurophysiological data for the lower limb. Knee-extensor fatigability and corticospinal responses differed between days 2, 14, and 21, with longer time to task failure in the mid-luteal phase. Fatigue is a known driver of poorer landing mechanics, so phase-related differences in fatigability matter for the end of a rehabilitation session, when drills are most demanding.

Motor Unit Control

Piasecki *et al.* (2023) showed that the nervous system can use a different motor unit strategy across the cycle while producing the same force. In rehabilitation, a patient may pass a strength test in any phase, yet the control strategy behind it may not be equally robust in every phase.

Other Cycle Characteristics

Symptoms

Symptom burden is a practical barrier. In 6,812 exercising women, mood change, fatigue, and cramps were each reported by over 80%, and symptoms limited exercise participation (Bruinvels *et al.*, 2021). In rehabilitation, this shows up as missed sessions and lower effort on testing days.

Hormonal Contraception

The two largest and best-quality studies in Herzberg *et al.* (2017) suggested hormonal contraceptives may protect against ACL injury, with up to about a 20% risk reduction reported. Combined oral contraceptives flatten endogenous fluctuations, so phase-based reasoning does not transfer directly to users.

Cycle Irregularity

Oligomenorrhoea and amenorrhoea, often linked to low energy availability, change the hormonal picture entirely and carry bone-health risk. They should be screened for, not trained around.

A PHASE-INFORMED FRAMEWORK FOR LOWER-LIMB REHABILITATION

The evidence supports individualising rehabilitation around the cycle, not prescribing one phase-based programme for every woman. The framework below follows that principle. It is consistent with the personalised physical therapy approach described by Васильцова (2022) and with the individualised approach recommended by McNulty *et al.* (2020).

Five Steps

1. *Screen at intake:* Record cycle length, regularity, last menstrual period, contraceptive type and a symptom score. Refer any amenorrhoea, oligomenorrhoea or very heavy bleeding for medical review before progressing load.
2. *Track through rehabilitation:* Use a calendar or app and, where decisions depend on phase, urinary luteinising hormone strips to confirm ovulation. Note symptoms daily on a simple 0–10 scale.
3. *Monitor control, not just capacity:* Add one sensitive control measure to routine strength testing: a single-leg drop landing scored for knee valgus, a square or side hop test, or knee joint position sense.
4. *Adjust the session, not the programme:* Keep weekly volume stable and change emphasis within sessions according to Table 3 and the patient's own data.
5. *Re-test in the same phase:* Schedule laxity measurement, hop testing and return-to-sport criteria in the same phase

Table 3: Suggested rehabilitation emphasis across menstrual cycle phases.

Phase	What may change	Rehabilitation emphasis	Watch for
Early follicular (menses)	Pain, cramps, fatigue; small, trivial dip in performance	Maintain strength work; manage symptoms; shorter, high-quality sessions; good baseline-testing window if symptoms allow	Missed sessions; low effort on tests
Late follicular	Rising oestrogen; higher neural excitability	Progress strength and power; introduce new motor skills and plyometrics	Progressing jumps too fast
Ovulatory	Peak anterior knee laxity (lagging the hormone peak by days)	Keep plyometric and cutting drills but add hamstring-led and hip-abductor activation first; strict landing cues; avoid fatigued high-risk drills at session end	Dynamic knee valgus; giving-way sensation
Mid- to late luteal	Progesterone-linked inhibition; possible premenstrual kinaesthesia deficit; altered fatigability; higher core temperature	Proprioceptive and balance training; controlled-tempo strength; monitor fatigue and hydration	Premenstrual symptoms; mood and sleep changes

Note: The table describes tendencies, not rules. If a patient's own landing scores and symptoms do not change across her cycle, she should be progressed normally.

each time, ideally the early-to-mid follicular phase, to remove hormonal noise from progress decisions.

Session Emphasis by Phase

Table 3 translates the phase-related changes described above into suggested rehabilitation emphases, together with what to watch for in each phase.

Hormonal Contraceptive Users

Combined oral contraceptives suppress the natural hormone peaks, so phase guidance does not apply. Track the active-pill and pill-free weeks instead, and note any symptom pattern around the withdrawal bleed. Progestin-only methods and hormonal intrauterine devices vary in whether ovulation is suppressed, so clinicians should track symptoms rather than assume a phase.

Worked Example (Illustrative Case)

A 23-year-old footballer, 7 months after ACL reconstruction, has a regular 30-day cycle and uses no contraception. Her hop limb symmetry index fluctuated between 86% and 93% across four weekly tests.

Phase tracking shows the two lowest results fell on cycle days 14 and 15. Re-testing every 30 days on day 7 gives a stable 91–92%. Her clinician now has a clean measure of progress. Landing-technique work and pre-activation are emphasised in the ovulatory window, and return-to-sport testing is booked for the follicular phase.

DISCUSSION

The central finding is that menstrual cycle effects on the lower limb are small for force but meaningful for control. That distinction explains much of the apparent contradiction in the literature. Studies that measure maximal strength generally find nothing (McNulty *et al.*, 2020; Colenso-Semple *et al.*, 2023). Studies that measure laxity, kinaesthesia, motor unit firing, or fatigability more often find phase effects (Ansdell *et al.*, 2019; Fridén *et al.*, 2006; Herzberg *et al.*, 2017; Piasecki *et al.*, 2023).

Rehabilitation targets exactly the control side. Its goal is not only a strong quadriceps but a knee that stays aligned under fatigue, at speed, and when ligament restraint is reduced. The risk profile described by Hewett *et al.* (2005), with excessive knee abduction during landing, is a control failure. Cycle-related changes in laxity and neural drive plausibly widen or narrow the margin for that failure.

The injury-timing data point in a consistent direction. Most studies place non-contact ACL injury risk in the pre-ovulatory and ovulatory window and lowest in the luteal phase (Herzberg *et al.*, 2017). The protective signal for hormonal contraceptives fits the same model: fewer hormone peaks, less laxity variation.

The Russian-language clinical literature reached a similar practical conclusion from a different direction. Васильцова (2022) argues that physical therapy programmes should account for cycle phase to optimise training and rehabilitation. The international data refine this: phase should

shape monitoring and emphasis, while individual response, not a universal calendar, should shape load.

Limitations of the Evidence

- *Phase verification:* Many studies estimated phase by counting days. Without hormone confirmation, a substantial share of tests labelled “ovulatory” or “luteal” may be misclassified, which is why verified phases are now the recommended standard (Elliott-Sale *et al.*, 2021).
- *Small samples:* Mechanistic studies often include 9–30 women, which limits power to detect modest effects.
- *Healthy volunteers:* Almost no studies track the cycle in patients during post-surgical rehabilitation. Injured or post-operative tissue may respond differently.
- *Contraceptive heterogeneity:* Different formulations, doses, and delivery routes are often grouped together.
- *Publication language:* Relevant Russian, Portuguese, and other non-English clinical work is seldom integrated into English-language reviews.

Priorities for Future Research

1. Prospective cohorts of women after ACL reconstruction, with hormonally verified phases and repeated laxity, landing and hop testing.
2. Randomised trials comparing phase-informed versus standard rehabilitation, with re-injury and return-to-sport rates as outcomes.
3. Validation of low-cost clinical tools, such as LH strips, symptom indices and smartphone landing analysis, for routine clinic use.
4. Studies in women using specific hormonal contraceptives and in women with irregular cycles.

CONCLUSION

Menstrual cycle characteristics are associated with lower-limb neuromuscular control more than with lower-limb strength. Anterior knee laxity peaks around ovulation, knee kinaesthesia and coordination vary between phases, and corticospinal drive, motor unit firing, and fatigability shift without changing maximal force.

For rehabilitation, three changes are justified now:

1. Record cycle phase, regularity, symptoms, and contraceptive use for every female patient.
2. Test progress and return-to-sport criteria in a consistent phase, using at least one control-sensitive measure.
3. Adjust session emphasis around each patient’s own pattern, with extra landing control and pre-activation around ovulation and attention to symptoms during menses and premenstrually.

Personalising rehabilitation to the menstrual cycle is not about restricting women. It is about measuring them accurately and protecting the knee when its passive restraint is lowest.

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Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely observed by the author.

Life Science Reporting

No life science threat was practised in this research.

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