原著論文

Influence of menstrual cycle on the relationship between joint laxity and dynamic balance ability

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Abstract：Background：General joint laxity（GJL）is a physical characteristic of joint hypermobility and decreased joint support function and may be involved in sports injuries and disorders of the trunk and lower limbs. Lee et al. and Shultz et al. reported that anterior knee laxity（AKL）increases during the ovulatory and luteal phases; however, Beynnon et al. reported no cyclic changes in AKL. As a result, no consensus on the knee joint has been formed. Sung et al. reported that knee and ankle joint laxity increases during ovulation, which may affect the ability to balance.

Purpose：This study aimed to clarify the effect of the menstrual cycle on AKL and balancing ability.

Methods：The subjects were adult women, and AKL and modified Star Excursion Balance Test（mSEBT）scores were measured.

Results：AKL and mSEBT were not significantly different between the menstrual cycles for both the dominant and non-dominant legs. The correlations between AKL and mSEBT examined for the menstrual cycle showed a trend of negative correlation in the non-dominant leg during the ovulatory phases of AKL and PM（p = 0.0863）.

Conclusion：In this study, a tendency for a negative correlation was found between AKL and mSEBT during the ovulatory phase, suggesting that those with high AKL during the ovulatory phase may have a relatively low dynamic balance ability.

Keywords：menstrual cycle, anterior knee laxity, dynamic balance ability, mSEBT

抄録：背景：Leeら，Shultzらの報告では排卵期，黄体期に膝前方弛緩性（AKL）が増加するといわれているが，Beynnonらの報告では周期的変化はみられないと報告しており，統一した見解は得られていない．Sungらの報告では，排卵期は膝関節や足関節の弛緩性が増大しバランス能力に影響する可能性があるといわれている．

目的：月経周期がAKLとバランス能力に与える影響を明らかにすることを目的とした．

方法：対象は成人女性とし，測定項目はAKL，modified Star Excursion Balance Test（mSEBT）とした．

結果：AKL，mSEBTは周期間の比較で有意差は認められなかった．AKLとmSEBTの相関関係は，排卵期の非利き脚で負の相関の傾向を認めた（p = 0.0863）．

結論：本研究では，排卵期でAKLとmSEBTの間に負の相関の傾向を認めたことから，排卵期でAKLが高値を示す者は動的バランス能力が相対的に低い可能性が推察された．

キーワード：月経周期，膝前方弛緩性，動的バランス，mSEBT

Ⅰ．Introduction

The anterior cruciate ligament（ACL）is a serious injury that frequently occurs in sports and necessitates a lengthy recovery period. It is frequently caused by abrupt deceleration, such as landing, or sudden changes in direction, and majority of them occur without contact [1)]. Such non-contact ACL injuries are known to be 2–9 times more frequent in women than in men [2, 3)], and it is useful to identify female athletes at high risk to prevent ACL injuries [4)]. Gender, anatomical factors, neuromuscular factors, genetic factors, race, and family

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history have been reported as risk factors for ACL injury [5], and an anatomical factor is reported to be generalized joint laxity (GJL) [6]. GJL is a physical characteristic in which the supportive function of the joints is reduced and hypermobility is observed [7], suggesting that GJL may be involved in sports injuries and disorders of the trunk and lower limbs [8-10]. In terms of the knee joint, increased anterior-posterior laxity of the tibiofemoral joint is associated with the risk of a first ACL injury[11,12], and regarding the menstrual cycle, anterior knee laxity (AKL) is said to increase during the ovulatory and luteal phases of menstruation[13-15]. Other reports, however, have not shown periodic changes, and a unified view has not been attained[16]. One reason for this is the lack of uniformity in period classification among previous studies[17]. The menstrual cycle can be divided into three main phases based on fluctuations in ovarian hormones : follicular (low estrogen, low progesterone), ovulatory (high estrogen, low progesterone), and luteal (high estrogen and high progesterone)[18]. Based on these facts, previous studies divided the menstrual cycle into three periods or measured the menstrual cycle in four periods, including the menstrual period[19,20]. To accurately determine the effects of hormonal fluctuations, it is necessary to examine the cycles in detail, and in the case of non-contact lower limb sports injuries, it is believed that impaired dynamic balance function of the lower limb is a risk factor for injury development[20,21]. Additionally, neuromuscular training has been reported to reduce the incidence of knee joint trauma in female athletes[22]. Knee and ankle joint laxities have been reported to increase during ovulation, which may affect balance ability[23]; however, few reports have quantitatively examined the relationship between joint laxity and balance ability.

Several factors influence the likelihood of trauma. Internal factors are some of the physical characteristics of athletes that make them more susceptible to trauma. Once they start competing, athletes are more susceptible to injury because of exposure to external risk factors[24,25]. The identification of risk factors is complex in sports, as many factors are interconnected[24]. These findings suggest that the risk of ACL injuries may increase due to the combination of multiple factors. Therefore, it is necessary to consider multiple factors for prevention.

In this study, we aimed to clarify the effects of the menstrual cycle on AKL and dynamic balance capacity as well as the variation in the relationship between AKL and dynamic balance capacity during the cycle. While conducting this study, the abstract and contents of the study were fully explained to all participants in advance, and their consent was obtained in writing. This study was approved by the Ethical Review Committee of the Tokyo Ariake University School of Medicine (No. 316).

Ⅱ. Materials and Methods

1. Participants

The subjects were 14 adult women who had been menstruating for at least three years and had menstrual cycles (Table 1). Those who did not show biphasic body temperature based on basal body temperature measurements were excluded.

Table 1. Physical Characteristics

	subject(14 people)
Age(years)	19.4±0.7
Height(cm)	155.2±3.8
Body weight(kg)	50.3±6.2
Menstrual cycle(days)	31.2±3.7

Mean±SD

2. Methods

1) Menstrual Cycle Recording

The menstrual cycle was divided into four phases based on basal body temperature measurements, and each phase was measured once. Basal body temperature was measured using WOMAN ℃ (TERUMO female thermometer, ET-C531PP, oral use only, manufactured by TERUMO). Basal body temperature was recorded every morning after waking up for one to two months before the start of the experiment, and the start and end dates of menstruation were also recorded on the recording sheet in addition to basal body temperature. The measurement timing was determined as follows : the menstrual phase was 3–4 days after the start of menstruation, the follicular phase was 3–4 days after the end of menstruation, the ovulatory phase was 1–2 days of the high-temperature phase of basal body temperature, and the luteal phase was between 5–10 days of the high-temperature phase[19].

2) Knee Laxity and Balance ability Measurement

(1) Anterior Knee Laxity (AKL)

The KT-1000 Knee Ligament Arthrometer (Med metric) (KT) is an instrument for measuring the anterior translation of the tibia relative to the femur and is used to measure the AKL[16, 26]. Based on the above information, we used KT as an objective measure of anterior knee sway. The subjects were placed in a supine position with the knee joint at 20° flexion. The patellar pad of the KT was fixed to the anterior surface of the patella, and the main unit was fixed to the anterior surface of the tibia with two belts attached. The patella was pressed against the femur and held in place with a belt to prevent internal/external rotation of the entire lower limb while the lower leg was pulled forward with the handle of the main body (Figure 1). Measurements were performed three times by the same examinee, and the average value was used as the data.

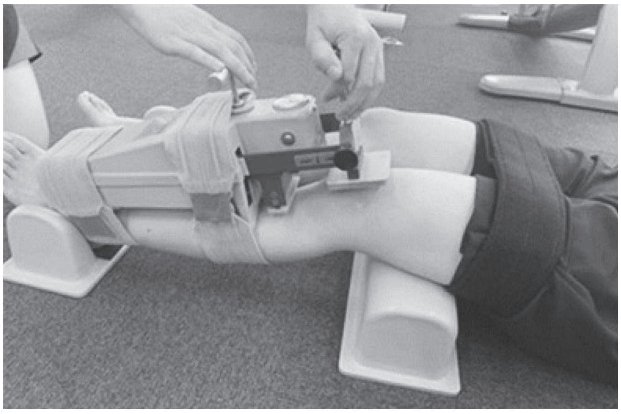

Fig 1. AKL measurement

(2) modified Star Excursion Balance Test (mSEBT)

Dynamic balance ability function is the ability to maintain the center of gravity in the basal plane of support during exercise[27], and loss of dynamic balance ability function is a risk factor for non-contact lower limb injuries[21]. mSEBT is a simple and easy-to-use method for evaluating dynamic balance ability and is frequently used in clinical practice[28]. In this study, we measured mSEBT as an index of dynamic balance ability.

Referring to Hertel et al. and Inoue et al., tapes were placed in three directions on the floor at an angle of 120°, and the starting limb position was a one-leg standing position in which the navicular tuberosity of the supporting side was located at the intersection of the three stick extensions (Figure 2)[29, 30]. Maximum reach was measured by marking the point reached by the most distal part of the foot with ink. The subjects were instructed to reach as far as possible, such that the heel of the supporting foot could not be lifted off the floor. The subjects were instructed not to place their weight on the heel of the foot that reached the floor. After each reach, the maximum distance that could be accomplished was measured when the subject returned to the standing position with both lower limbs in the starting position. The direction of reaching was measured in the order of anterior (ANT), posteromedial (PM), and posterolateral (PL), with the supporting side as the reference, and the average value was recorded three times. Measurements were divided by the length of the subject's spina malleolar distance (SMD) and the reach rate (%) was calculated. Subjects practiced sufficiently in each direction, and after resting for a few minutes, measurements were taken after confirming that

Fig 2. mSEBT with reach directions labeled in reference to left stance foot.

the subjects were not fatigued.

Reach rate (%) = distance reached (cm) / SMD (cm)

3. Statistical Analysis

Measured data are expressed as mean ± standard deviation. All statistical analyses were performed usingOne-way ANOVA was used to compare menstrual cycles, and the Tukey-Kramer method of multiple comparison testing was used as a post-test. The relationship between AKL and mSEBT was examined using JMP Pro16.2 (SAS Institute, Cary, NC, USA) the Pearson product-rate correlation coefficient. Statistical significance was set at $p < 0.05$.

Ⅲ. Result

1. AKL

A comparison between menstrual cycles showed no significant difference for both the dominant and non-dominant legs (Table 2).

2. mSEBT

A comparison between menstrual cycles showed no significant difference for both the dominant and non-dominant legs in any of the three directions (Table 3).

3. Relationship between AKL and mSEBT

The correlations between AKL and mSEBT examined for the menstrual cycle showed a trend of negative correlation in the non-dominant leg during the ovulatory phases of AKL and PM (Table 4).

Ⅳ. Discussion

This study aimed to clarify the effects of the menstrual cycle on AKL and dynamic balance ability in adult women with cyclic menstruation for more than 3 years after menarche and the relationship between AKL and dynamic balance ability during the menstrual cycle. The results showed that there was no significant difference between AKL and mSEBT in the comparison of cycle duration, suggesting that the menstrual cycle may have little influence on AKL and mSEBT. Previous studies have not provided a unified perspective of the menstrual cycle effects on AKL. The reasons for this include the fact that students with low physical activity levels who were at low risk of ACL injury were included in the study, and the effects of physical predispositions such as ankylosing knees and hormone concentrations were not examined[31]. In a previous study, AKL was reported to increase during the ovulatory phase in individuals with ankylosing knees[31]. Furthermore, as there are individual differences in the magnitude and timing of fluctuations in female hormones[32], the measurement of hormone concentrations is considered necessary. It has been reported that estrogen receptors exist in the human ACL, that female hormones affect the tissue structure of the ACL, and that AKL increases during the ovulatory and luteal phases. Recently, it was reported that the luteal phase of the ACL is affected by the secretion of relaxin from the ovary, which affects the ACL and joint laxity[3, 33]. Moreover, receptors for relaxin are present only in women with ACL[33], and a 4-fold higher risk of ACL injury has been reported when relaxin-2 levels are > 6 pg/mL[3]. A limitation of this study is that we do not know how sex hormones change with AKL and mSEBT, and we cannot examine the effects of

Table 2. AKL

	Dominant leg	Non—dominant leg
	Mean ± SD (mm)	
Menstrual period	7.1±1.9	6.5±2.0
Follicular phase	6.7±2.3	7.0±2.8
Ovulation period	6.6±2.1	6.7±2.1
Luteal phase	6.3±2.3	6.9±2.3

Table 3. mSEBT

		Dominant leg	Non—dominant leg
		Mean ± SD (%)	
ANT	Menstrual period	0.87±0.08	0.86±0.08
	Follicular phase	0.86±0.08	0.88±0.07
	Ovulation period	0.88±0.06	0.87±0.06
	Luteal phase	0.87±0.07	0.87±0.08
PM	Menstrual period	0.90±0.11	0.90±0.12
	Follicular phase	0.89±0.10	0.91±0.11
	Ovulation period	0.93±0.09	0.94±0.08
	Luteal phase	0.92±0.08	0.91±0.07
PL	Menstrual period	0.81±0.10	0.79±0.08
	Follicular phase	0.78±0.10	0.78±0.09
	Ovulation period	0.84±0.08	0.83±0.08
	Luteal phase	0.79±0.07	0.79±0.06

Table 4. Relationship to AKL and mSEBT

Dominant leg		ANT		PM		PL	
		r	p	r	p	r	p
AKL	Menstrual period	0.0128	0.9654	—0.2032	0.4859	—0.2736	0.3439
	Follicular phase	—0.0119	0.9679	0.0499	0.8656	—0.1863	0.5236
	Ovulation period	0.0141	0.9620	—0.2249	0.4395	—0.3845	0.1747
	Luteal phase	0.1566	0.5929	0.1819	0.5336	—0.0561	0.8489

Non—dominant leg		ANT		PM		PL	
		r	p	r	p	r	p
AKL	Menstrual period	0.1644	0.5744	—0.0685	0.8161	—0.1882	0.5194
	Follicular phase	—0.1086	0.7117	—0.1412	0.6302	—0.3145	0.2735
	Ovulation period	—0.3858	0.1730	—0.4747	0.0863	—0.4697	0.0902
	Luteal phase	0.1796	0.5389	—0.0793	0.7875	—0.0496	0.8662

sex hormones. As previous studies have inferred that sex hormones influence ligament laxity, it is necessary to compare the results of these studies with those of hormonal kinetics.

Non-contact ACL injuries are known to be 2–9 times more frequent in women than in men [2, 3], and many factors are believed to contribute to lower extremity injuries in female athletes, including neuromuscular control problems, psychological and genetic factors[34], and anatomical factors such as bone morphology[35]. Hewett et al. reported a decrease in the incidence of knee joint injuries when female athletes were given neuromuscular training[36]. It has also been reported that ACL injuries occur more frequently in women in the nondominant leg[37]. In this study, we examined the correlation between AKL and mSEBT and found a trend of negative correlation during the ovulatory period. This suggests that the dynamic balancing capacity may be relatively low during the ovulatory period when AKL is high. Wojtys et al. (1998) suggested that ACL injury in women may occur during 10–14 days (ovulatory period) when estrogen concentrations are high, and may be less likely to occur during 1–9 days (follicular period) when estrogen concentrations are low[38]. In a systematic review by Hewett et al., the follicular phase was defined as days 1–9 of the cycle, ovulatory phase as days 10 to 14, and luteal phase as days 15 or later, to organize the literature ; seven reports reported an increase in non-contact ACL injury during the first half of the cycle, before ovulation[36]. These findings suggest that the relationship between AKL and mSEBT observed in this study may be one of the factors contributing to the occurrence of such injuries during ovulation.

V. Conclusion

In this study, the menstrual cycle was divided into four phases, and a trend of negative correlation was observed between AKL and mSEBT during the ovulatory phase. Based on these findings, those with high AKL during the ovulatory period may have relatively low dynamic balance ability capacity, which may lead to injuries during the ovulatory period.

Conflicts of interest

The authors declare no conflicts of interest regarding the publication of this paper.

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References

1) Olsen OE, Myklebust G, Engebretsen L, et al. Injury mechanisms for anterior cruciate ligament injuries in team handball. A systematic video analysis. Am J Sports Med. 2004 ; 32 (4) : 1002–12.
2) Arendt EA, Agel J, Dick R. Anterior cruciate ligament injury patterns among collegiate men and women. J Athl Train. 1999 ; 34 (2) : 86–92.
3) Dragoo JL, Castillo TN, Braun HJ, et al. Prospective correlation between serum relaxin concentration and anterior cruciate ligament tears among elite collegiate female athletes. Am J Sports Med. 2011 ; 39 (10) : 2175–80.
4) Kunita Y,Kaneko M,Ohmi Y,et al. Association between femoral anteversion and the risk of anterior cruciate ligament injury in female athletes. Journal of the Japanese Society of Clinical Sports Medicine. 2016 ; 24 (3) : 390–395.
5) Griffin LY, Agel J, Albohm MJ, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. J Am Acad Orthop Surg. 2000 ; 8 (3) : 141–50.
6) Sikvers HJ, Mandelbaum BR. Prevention of anterior cruciate ligament injury in the female athlete. Br J Sports Med. 2007 ; 41 (1) : i52–i59.
7) Grahame R. Joint hypermobility and genetic collagen disorders : are they related?. Arch Dis Child. 1999 ; 80 (2) : 188–191.
8) Smith R, Damodaran A, Swaminathan S, et al. Hypermobility and sports injuries in junior netball players. Br J Sports Med. 2005 ; 39 (9) : 628–631.
9) Takeda N, Watanabe H, Torii S. The relationship between knee laxity and general Joint looseness in female basketball players. physical fitness science. 1997 ; 46 : 273–278.
10) Torii S, Torii N, Watanabe H. Relationship between major joint injury and general joint laxity in collegiate american football players. physical fitness science. 2004 ; 53 : 503–508.
11) Uhorchak JM, Scoville CR, Williams GN, et al. Risk factors associated with noncontact injury of the anterior cruciate ligament : a prospective four-year evaluation of 859 west point cadets. Am J Sports Med. 2003 ; 31 (6) : 831–42.
12) Vacek PM, Slauterbeck JR, Tourville TW, et al. Multivariate analysis of the risk factors for first-time noncontact ACL injury in high school and college athletes : A prospective cohort study with a nested, matched case-control analysis. Am J Sports Med. 2016 ; 44 (6) : 1492–501.
13) Lee H, Petrofsky JS, Daher N, et al. Anterior cruciate ligament elasticity and force for flexion during the menstrual cycle. Med Sci Monit. 2013 ; 19 : 1080–1088.
14) Shultz SJ, Levine BJ, Nguyen AD, et al. A comparison of cyclic variations in anterior knee laxity, genu recurvatum and general joint laxity across the menstrual cycle. J Orthop Res. 2010 ; 28 (11) : 1411–1417.
15) Shultz SJ, Sander TC, Kirk SE, et al. Sex differences in knee joint laxity change across the female menstrual cycle. J Sports Med Phys Fitness. 2005 ; 45 (4) : 594–603.
16) Beynnon BD, Bernstein IM, Belisle A, et al. The effect of estradiol and progesterone on knee and ankle joint laxity. Am J Sports Med. 2005 ; 33 (9) : 1298–304.
17) Janse de Jounge XA .Effects of the menstrual cycle on exercise performance. Sports Med. 2003 ; 33 (11) : 833–51.
18) Higuchi A, Honma M, Yamamoto M, et al. Changes in ankle function of university female volleyball players during the menstrual cycle : Muscle strength, joint position sense and flexibility. physical therapy science. 2017 ; 32 (4) : 503–507.
19) Sasaki M, Edama M, Okuyama R, et al. Changes in patellar tendon length during passive knee flexion in the menstrual cycle. physical fitness science. 2018 ; 67 (2) : 199–204.

20) Fousekis K, Tsepis E, Vagenas G. Intrinsic risk factors of noncontact ankle sprains in soccer : a prospective study on 100 professional players. Am J Sports Med. 2012 ; 40 (8) : 1842-50.
21) Plisky PJ, Rauh MJ, Kaminski TW, et al. Star excursion balance test as a predictor of lower extremity injury in high school basketball players. J Orthop Sports Phys Ther. 2006 ; 36 (12) : 911-9.
22) Hewerr TE, Lindenfeld TN, Riccobene JV, et al. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. Am J Sports Med. 1999 ; 27 (6) : 699-706.
23) Sung ES, Kim JH. The influence of ovulation on postural stability (Biodex Balance System) in young female. J Exerc Rehabil. 2018 ; 14 (4) : 638-642.
24) Meeuwisse WH. Assessing causation in Sport Injury : A multifactorial model. Clin J Sport Med. 1994 ; 4 (3) : 166-170.
25) Meeuwisse WH, Tyreman H, Hagel B, et al. A dynamic model of etiology in sport injury : the recursive nature of risk and causation. Clin J Sport Med. 2007 ; 17 (3) : 215-9.
26) Shultz SJ, Gansneder BM, Sander TC, et al. Absolute serum hormone levels predict the magnitude of change in anterior knee laxity across the menstrual cycle. J Orthop Res. 2006 ; 24 (2) : 124-31.
27) Butler RJ, Southers C, Gorman PP, et al. Differences in soccer players' dynamic balance across levels of competition. J Athl Train. 2012 ; 47 (6) : 616-620.
28) Kurihara Y, Karasuno H, Matsuda T, et al. Kinematic factors affecting the lower limb reach distance of the modified star excursion balance Test —for female collegiate athletes—. Journal of the Japanese Society of Clinical Sports Medicine. 2020 ; 28 (2) : 321-327.
29) Hertel J, Braham RA, Hale SA, et al. Simplifying the star excursion balance test : analyses of subjects with and without chronic ankle instability. J Orthop Sports Phys Ther. 2006 ; 36 (3) : 131-7.
30) Inoue Y, OtaniaY, Naruse S, et al. Relationships between lower-extremity muscle strength and the modified star excursion balance test in adolescent female soccer players. physical therapy science. 2015 ; 30 (6) : 853-856.
31) Maruyama S, Yamazaki T, Sato Y, et al. Relationship between anterior knee laxity and general joint laxity in the menstrual cycle. Orthop J Sports Med. 2021 ; 9 (3) : 1-7.
32) Park SK, Stefanyshyn DJ, Ramage-Loitz B, et al. Changing hormone levels during the menstrual cycle affect knee laxity and stiffness in healthy female subjects. Am J Sports Med. 2009 ; 37 (3) : 588-98.
33) Dragoo JL, Lee RS, Benhaim P, et al. Relaxin receptors in the human female anterior cruciate ligament. Am J Sports Med. 2003 ; 31 : 577-584.
34) Smith HC, Vacek P, Johnson RJ, et al. Risk factors for anterior cruciate ligament injury : a review of the literature—part 2 : hormonal, genetic, cognitive function, previous injury, and extrinsic risk factors. Sports Health. 2012 ; 4 (2) : 155-161.
35) Smith HC, Vacek P, Johnson RJ, et al. Risk factors for anterior cruciate ligament injury : a review of the literature - part 1 : neuromuscular and anatomic risk. Sports Health. 2012 ; 4 (1) : 69-78.
36) Hewett TE, Zazulak BT, Myer GD. Effects of the menstrual cycle on anterior cruciate ligament injury risk ; a systematic review. Am J Sports Med. 2007 ; 35 (4) : 659-68
37) Ihara H, Takayama M, Fukumoto T, et al. Gender difference and laterality in ACL non-contact injuries. physical therapy science. Orthopedics and Disaster Surgery. 2005 ; 54 (2) : 241-246.
38) Wojtys EM, Huston LJ, Lindenfeld TN, et al. Association between the menstrual cycle and anterior cruciate ligament injuries in female athletes. Am J Sports Med. 1998 ; 26 (5) : 614-9.