Dynamic Knee Stability: Single Leg Hop Tests and Hamstring/Quadriceps Ratio during Menstrual Cycle in Female Athletes

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ABSTRACT

Background: *Knee instability is one of the hallmarks of sport injuries in female athletes. The purpose of this study was to determine if dynamic knee stability characteristics specifically the single-leg hop tests and the hamstring eccentric / quadriceps concentric ratio in female athletes are altered across the menstrual cycle phases.* ***Materials and Methods:*** *Fifty adult female athletes were recruited for this study, their age ranged from 18-30 years. Each individual was tested three times during the phases of the normal female menstrual cycle (Early follicular phase, within ovulation days, and mid luteal phase) to determine dynamic knee stability through the assessment of the hamstrings to quadriceps ratio (HQR) tested by the Biodex isokinetic system and through the functional performance test single leg-hopping tests.* ***Results:*** *HQR at 60°/sec showed no significant difference among the three phases of menstrual cycle, while HQR at 180°/sec showed significant difference between follicular phase and luteal phase. The scores of all four Single leg hop tests showed significant change during menstrual phases with a greater difference between the follicular and the luteal phase.* ***Conclusion:*** *Dynamic knee stability characteristic specifically the Hamsting ecc/ quadriceps conc at 180°/ sec and single-leg hop tests were altered across the menstrual cycle with the greater decrease in the mid-luteal phase which coincide with high level of estrogen and progesterone. As such, female athletes are at risk of knee injuries in the mid luteal phase.*

Key words: *Dynamic knee stability, hop test, menstrual cycle, hamstring/quadriceps ratio.*

INTRODUCTION

Sports are overtime becoming a significantly important part of people's daily lives. Female athletes are more prone to knee injuries as compared to males by two to eight times when participating in the same non-contact activities[18]. The higher incidence of knee injuries in females has been attributed to anatomical differences, biomechanical characteristics, ligament laxity, movement technique, muscular strength imbalances, and sex hormone influences[7,22,26,37].

Dynamic knee stability is the ability of the knee joint to remain stable when it is exposed to the rapidly changing loads that occur during activity[36]. Dynamic stability depends on integration of articular geometry, soft tissue restraints, and the loads applied to the joint through weight bearing and muscle activation[36]. The sudden loss of control of the knee joint in a weight bearing position is referred to functional instability[36].

It was suggested that the eccentrically co-contracting hamstrings have a dynamic role in maintaining the stability of the knee during forceful knee extension. An H ecc/Q con ratio of 1.0, which has been labeled the point of equality, indicates that the eccentrically acting hamstrings have the ability to fully brake the action of the concentrically contracting quadriceps. During fast knee extension and towards full extension the eccentrically acting hamstrings have been shown to produce a braking joint flexor moment that is equal to or greater than the extensor moment exerted by the quadriceps[1,2]. This would help to reduce anterior displacement of the tibia on the femur and prevent hyperextension of the knee. Evaluation of isokinetic eccentric antagonistic strength relative to concentric agonist strength may provide a relationship of value in describing the maximal potential of the antagonistic muscle group and is useful in determining an injury risk.

The influence of the ovarian steroid hormones is a hypothesized causal factor for the prevalence of knee injuries in female athletes. Females are exposed to varying concentrations of these hormones throughout the menstrual cycle, and the hormones can affect visceral and non-visceral tissues such as skeletal muscle and connective tissue[38].

The menstrual cycle consists of two phases: the Follicular Phase approximately 14 days starting by the menstrual flow which lasts 3 to 5 days and end by ovulation (day 10-14). It is accompanied at the beginning by low levels of estradiol and progesterone which increase gradual to reach its peak at ovulation. During ovulation, levels of estrogen fall while progesterone begins to increase. The luteal phase begins with ovulation and ends with the menstrual flow and usually lasts 14 ± 2 days. Large amounts of progesterone as well as estrogen are produced to reach its peak at day 20-25 and then it becomes to decrease till the start of the menstrual flow at day 28-32. The changes in the levels of these hormones have some effects on bones, soft tissues, central nervous system and connective tissue. In fact both animals and human studies have shown that higher estrogen levels causes increased knee laxity[6,14,25,35].

Three new studies connect knee joint laxity and a woman's menstrual cycle.

In one study[29] 14 of 26 subjects showed the greatest amount of knee laxity during the ovulation phase, while 10 others had the greatest laxity during the follicular phase and 2 subjects during the luteal phase. In this study, women's estradiol and progesterone levels were measured in the follicular phase, at ovulation and during the luteal phase of their menstrual cycle. Their knee laxity was measured at each phase using a knee arthrometer and they were asked to perform several athletic movements like quick cuts, or sharp jumps. The study found 12.7% greater knee laxity during ovulation at a load of 89N and 8% at maximum manual load, when compared with knee laxity at other phases of the menstrual cycle.

In a second related study[30], knee laxity again correlated positively with knee joint loads across the menstrual cycle. The researchers concluded that increased knee joint laxity during the menstrual cycle may be a potential risk factor for ACL tears among certain female athletes.

In the third study[31], the same team of researchers showed that changes in knee joint laxity through the menstrual cycle do, in fact, change knee joint loading during select high-risk athletic twists and turns. Although, some researchers said knee joint laxity may not explain the higher incidence of females' ACL injury, they suggested that muscle strength and dynamic stability are more important[8].

The bottom line is that to stave off ACL injuries in female athletes. It is critical and crucial and it is important to know when athletes have more laxity and dynamic instability to be more cautious with those athletes at that time during their menstrual cycle.

However, in all previous studies the stability of the knee was measured statically using knee arthrometer (KT 1000) to determine the anterior translation of the tibia during the menstrual cycle. However, static tibial translation does not correlate with functional outcome[21,32] or quadriceps or hamstring muscle strength in patients with ACL deficiency[32]. Furthermore, the static tibial translation does not correlate with the dynamic tibial translation, i.e. translation during activity[24]. As knee stability depends on static and dynamic factors and as static stability doesn't correlate with dynamic stability, it becomes necessary to determine dynamic knee stability characteristics during menstrual cycle.

Thus the purpose of this study was to determine if dynamic knee stability characteristics specifically the single-leg hop test and the hamstring ecc / quadriceps conc ratio in female athletes are altered across the menstrual cycle phases.

MATERIALS AND METHODS

Subjects

Fifty single adult female athletes ranging in age from 18–30 years, with height ranged from 157 to 174 cm and weight ranged from 48 to 74 kg and who reported normal menstrual cycles (28-32 days) participated in the study. In order to participate the following Inclusion criteria were met: 1) no suffering from any orthopedic, neurological, cardiopulmonary or gynecological disorders, 2) single, 3) participating in different and varied sport activities. Participants were excluded if they experienced knee injury at the time of the testing, or having history of previous surgeries or traumas in lower limbs. Subjects taking drugs or medications that may affect normal female menstrual cycle or sex hormones were also excluded. All subjects completed a medical and menstrual cycle history inquiring about inclusion criteria as well as an approved informed consent.

Procedures

Phases of the menstrual cycle were defined based on the first day of menses. Subjects reported for initial knee dynamic stability testing at the days of early follicular phase (first 5 days of the menstrual cycle). Within ovulation days (13^{th}, 14^{th} and 15^{th} days), subjects reported for a second knee dynamic stability testing session. A third testing session was conducted at mid-luteal phase (days from 20^{th} to 25^{th}) of the menstrual cycle.

The days of testing were selected to determine if changes in hormonal levels would contribute to corresponding variations in knee dynamic stability across the menstrual cycle. Specifically, the determined time points coincided with low levels of estradiol and progesterone (menses), elevated estradiol and low progesterone (post-ovulatory), and elevated estradiol and progesterone (mid-luteal).

All measurements were recorded by the same assessor to avoid inter-tester variability. All examinations' results were recorded from the dominant leg performance. The dominant leg was defined as the leg the subject would self-select to kick a ball for maximum distance.

Isokinetic hamstring quadriceps ratio (HQR) testing:

The Biodex Isokinetic System 3 had been used to assess the isokinetic hamstring quadriceps ratio. HQR was measured at two angular velocities: 60°/sec, and 180°/sec. Previous researchers have established the mechanical reliability of the Biodex system 3 and have shown that reciprocal, concentric peak torque measures obtained at 60°/sec and 180° /sec are very consistent from day to day when a standardized protocol is used[15]. The dynamic control ratio, defined as Hamstring (eccentric) to Quadriceps (concentric) of knee extension[19,34] was the selected mode used to examine HQR.

Subjects were seated in the biodex chair and secured using thigh, pelvic and torso straps to minimize accessory and compensatory movement during HQR testing. The seat orientation was set at 0°, the seatback tilt was set at 15°, and knee axis of rotation was determined by a line drawn in the sagittal plane through the femoral condyles. The standard knee attachment device was secured to the leg, so that the inferior border of the pad was placed on the superior border of the medial malleolus. Once the subject was secured in the chair, the ranges of motion limits were determined via goniometry, while weight of limb and gravity factor was calculated by the instrument. The starting position was 90° of knee flexion, and the endpoint was 0° of full knee extension. Three trials were performed to test eccentric hamstrings to concentric quadriceps muscular contraction at angular velocity of 60°/sec and the best record was saved by the Biodex system 3 software.

Single-leg hop tests:

The series of four single leg hopping tests was administered in accordance with the protocols outlined by Noyes et al. (1991)[28], Barber et al.(1990)[5] and Daniel et al. (1988)[10] to test the dynamic knee stability. The tests incorporate a variety of movement principles (i.e. direction change, speed, acceleration, deceleration, and rebound) that mimic the demands of dynamic knee stability. The tests were a single hop for distance, a timed hop, a triple hop for distance, and a crossover hop for distance. The hop testing course was constructed on low-pile, rubber backed carpet glued over concrete floor. The course consisted of a 6 meters long × 15 cm wide marking placed on the floor[33]. For each hop test, the subjects performed three trials. For each set of tests, a rest period was offered between types of hop tests (up to 2 minutes) and between individual hop test trials if needed (typically less than 30 seconds was sufficient). Single-leg hop tests can be measured objectively and have been shown to be reliable[5,10,28].

The single Hop for Distance was performed while the subject stood on the leg to be tested and the hands placed behind the back, hopped and landed on the same leg. The distance hopped, measured at the level of the great toe was measured in centimeters by a standard tape measure. Three trials were performed, and the best score was recorded. The timed 6 m hop was performed while the subject was instructed to perform large one-legged hops in series over the total distance. A standard stopwatch was used to record time. The stop watch was started when a subject's heel lifted from the starting position and was stopped the moment the tested foot passed the finish line. The time was measured in seconds. Three trials were performed, and the best score was recorded.

The triple hop for distance was performed while the subjects were instructed to stand on one leg and perform 3 consecutive hops as far as possible landing on the same leg. The total distance for three consecutive hops was recorded. Finally, Cross-Over Hop for Distance was performed over a 15 cm strip on the floor. The subjects hopped forward 3 times while alternately crossing over a marking. The total distance hopped forward was recorded. Subjects were instructed to position themselves such that the first of the 3 hops was lateral with respect to the direction of crossover. Three trials were performed, and the best score was recorded.

Statistical design

Statistical analyses were performed using SPSS 16.0 version statistical software (SPSS, Inc., Chicago, IL, USA). Separate repeated measures analyses of variance (ANOVA) were performed for each dependent variable (HQR at angular velocity of 60°/sec, HQR at angular velocity of 180°/sec, distance hopped in single hop for distance measured in centimeters, timed hop measured in seconds, triple hop for distance and cross-over hop for distance measured in centimeters) to determine significant differences between the three menstruation phases. The within subject factor was menstrual cycle phase (3levels: early follicular, within ovulation and mid-luteal phase). A Bonferroni post hoc analysis was performed when applicable. Statistical significance was established at $\alpha<.05$.

RESULTS

HQR at angular velocity of 60°/sec and 180°/sec:

Means and standard deviations for HQR at angular velocity of 60°/sec and 180°/sec are shown in Figure 1 and table 1. Statistical analysis revealed no significant difference in HQR at angular velocity of 60°/sec between the three phases (F=1.31, P=0.27) while there was a significant difference in the HQR at angular velocity of 180°/sec (F=5.09, P=0.007). Bonferroni post hoc tests revealed the difference between the early follicular phase and mid luteal phase. This finding indicates that menstrual cycle phases have no significant effect on HQR at angular velocity of 60°/sec but have effect at angular velocity of 180°/sec.

Single-leg hop tests

Table 1. Shows the results of the four single-leg hop tests (single hop for distance, a timed hop, a triple hop for distance, and a crossover hop for distance) used to assess the dynamic knee stability. There was a significant difference between all the measures of single leg hop tests during menstrual phases. For single hop for distance and 6 m timed hop Bonferroni post hoc tests indicated that the scores of the tests on early follicular phase was significantly different from those of within ovulation days and mid luteal phase. For triple hop for distance, and a crossover hop Bonferroni post hoc tests indicated that the scores of the tests on mid luteal phase were significantly different from those of early follicular phase and within ovulation days, while there were no significant difference between the scores of early follicular phase and within ovulation days.

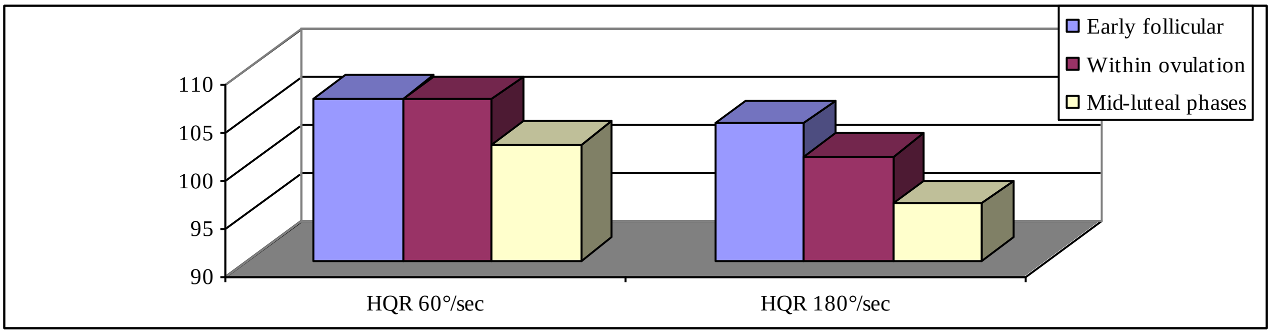

Fig. (1): Means of HQR at angular velocity of 60°/sec and HQR at angular velocity of 180°/sec at early follicular phase, within ovulation days and mid luteal phase.

Table (1): Means and standard deviations and p value, for HQR and single-leg hop tests in early follicular, within ovulation and mid-luteal phases (mean± SD).

Variable	Early follicular	within ovulation	mid-luteal	P value
HQR 60°/sec	106.83±21.62	106.77±16.34	102.13±16.67	0.27
HQR 180°/sec	104.27±14.0	100.82±14.53	95.96±13.28	0.007*
Single hop	91.38±11.52	85.88±12.43	70.1±15.22	0.0001*
Timed hop	3.24±0.4	3.44±0.52	4.59±0.6	0.0001*
Triple hop	273.56±35.66	268.74±48.81	200.1±25.24	0.0001*
Cross-over hop	183.55±32.77	174.03±25.99	124.55±13.72	0.0001*

*significant difference

DISCUSSION

Dynamic knee stability was measured in this study by six parameters: HQR at angular velocity of 60°/sec, HQR at angular velocity of 180°/sec, Single Hop for Distance, Timed Hop, Triple Hop, and Cross over Hop for distance. HQR was chosen as a parameter to represent dynamic knee stability as muscle balance is one of the components needed to maintain knee stable during movement and it helps to reduce anterior displacement of the tibia on the femur and prevent hyperextension of the knee. According to the report of Rosene et al. (2001)[34], and Holm et al. (1994)[20] the flexor to extensor strength balance is important in overall knee stabilization.

The series of four hop tests were also chosen as a measure of dynamic stability according to the finding of Reid et al. (2007)[33] who reported that a single hop for distance, a timed hop, a triple hop for distance, and a crossover hop for distance provide reliable and valid performance based outcome measures for knee functional stability. Fitzgerald et al. (2001)[13] suggested that single leg hop tests reflected related changes in knee functional stability. Knee dynamic stability needs limb power and strength that was proved by Hamilton et al. (2008)[15] who found that triple hop for distance is a valid test of lower limb power and strength in National Collegiate Athletic Association Division I soccer players.

The results of the present study indicated that all parameters tested change significantly through the menstrual cycle of female athletes except the HQR at 60^{o}/sec. These findings comes in agreement with that of Buchanan et al. (2003)[9] who found no differences in the isokinetic Hamstring to Quadriceps ratios of males versus females basketball players and suggested that there is no sex related differences or interactions for this measures were valid. Abt et al. (2007)[3] had also found no significant change in HQR at both 60^{o}/sec and 180^{o}/sec during the different phases of menstrual cycle. Similarly, The HQR testing results in the current study are consistent with Elliot et al.,[12] Friden et al.,[14] Janse de Jonge et al.,[23] and Hertel et al.,[17].

There are so many reports in the literature of associations between noncontact knee injuries and the phase of the menstrual cycle, as women demonstrate changes in strength, relaxation time and muscular fatigability during the menstrual cycle[18]. This was in support to our result that revealed changes in HQR at 180^{o}/sec with a significant decrease of the ratio from early follicular phase at which there is low levels of estradiol and progesterone to mid luteal phase at which estradiol and progesterone were elevated. This indicates that women are more liable to knee injuries during elevation of estradiol and progesterone at the mid-luteal phase and especially in high speed activities.

The single-leg hop tests were used as measure of dynamic knee stability because they incorporate a variety of movement principles that represent the demands of dynamic knee stability. Significant decrease in the score of all 4 hop tests were demonstrated across the menstrual cycle indicating that fluctuation of hormones level influence the subject performance. The greater decrease in scores was mainly in the mid-luteal phase which coincides with the high level of estrogen and progesterone. These findings could explain those of Wojtys et al. (1998)[37] who observed lower number of ACL injuries during the follicular (menses) phase of the menstrual cycle which coincide with low level of esterogen and progesterone. The current results also explain the finding of Myklebust et al. (1998)[27] who demonstrated greater number of ACL injuries in women's handball in the premenstrual period (luteal phase) that is during the high level of estrogen and progesterone. The female hormones estrogen and progesterone may indeed play a role in the increased injury rates in female athletes.

The results of this study agree with that of Heitz et al. (1999)[16] who found that hormonal changes experienced during the menstrual cycle may have an increased knee laxity effect in women, and the greatest knee laxity was associated with the luteal phase. Heitz et al. (1999)[16] have confirmed the importance of considering female sex hormones as one of several factors that may be contributing to the female knee injury. It has not been definitively determined at what phase in the menstrual cycle women may be at higher risk of injury. However, many studies provide an important correlation between knee injury and the menstrual cycle[18].

A limitation of this study is that HQR ratio and single-leg hop tests measurements were only taken on three separate days across the menstrual cycle. Verifying estrogen concentrations in the blood is vital to verify that HQR ratio and single-leg hop tests measurements are truly being taken at a maximal elevated level. Our study did not take blood samples and analyze estrogen concentrations to verify that our ovulation testing session was truly performed at an elevated hormone level. Daily blood draws across a complete menstrual cycle would be needed to identify hormone trends and correlate estrogen levels to dynamic knee stability parameters.

Further studies are recommended to measure other dynamic knee stability characteristics with daily measure of monthly hormonal fluctuation in female athletes.

Conclusion

Dynamic knee stability characteristic specifically the Hamsting ecc/ quadriceps conc at 180^{o}/ sec and single-leg hop tests were altered across the menstrual cycle with the greater decrease in the mid-luteal phase which coincide with high level of estrogen and progesterone. As such, female athletes are at risk of knee injuries in the mid luteal phase.

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الملخص العربي

ثبات الركبة الديناميكي : اختبارات القفز على قدم واحدة
ومعدل تناسب بين العضلة الخلفية والأمامية للركبة أثناء الدورة الشهرية عند الإناث الرياضيات

خلفية:عدم ثبات الركبة هو واحد من السمات المميزة للإصابات الرياضية لدى الرياضيين الإناث. وكان الغرض من هذه الدراسة هو تحديد ما إذا كانت الخصائص الد ينامية لثبات الركبة تحديدا اختبار القفز على قدم واحدة و اختبار معدل التناسب الأيزوكينيتيكى بين العضلة الخلفية والعضلة الأمامية العاملتين على الركبة عند سرعة دائرية بقيمتى 60°/ثانية و180°/ثانية عبر مراحل الدورة الشهرية . الأساليب : أجريت هذه الدراسة على خمسين من ممارسات الرياضة البالغات واللاتي تتراوح أعمارهن ما بين 18 إلى 30 عاماً تم اختبار كل فرد ثلاث مرات خلال مرحلة من مراحل الدورة الشهرية العادية (المرحلة الأولى : التحوصل ، المرحلة الثانية : التبويض ، والمرحلة الثالثة : مرحلة ما قبل الحيض) وذلك باستخدام وسيلتي تقييم ، الأولى : باستخدام نظام بيودكس 3 كوسيلة تقييم لمعدل التناسب الأيزوكينيتيكى بين العضلة الخلفية والعضلة الأمامية العاملتين على الركبة عند سرعة دائرية بقيمتي 60°/ثانية و180°/ثانية . أما الثانية : فباستخدام اختبار الأداء الوظيفي للركبة (أربعة من اختبارات القفز على قدم واحدة) النتائج : أظهرت النتائج انخفاض ذو دلالة إحصائية في معدل التناسب الأيزوكينيتيكى بين العضلة الخلفية والعضلة الأمامية عند سرعة دائرية و180°/ثانية في مرحلة ما قبل الحيض و ك ذلك في الأربعة اختبارات للقفز على قدم واحدة أظهرت النتائج انخفاض ذو دلالة إحصائية بين كل مرحلة و الأخرى . *الخلاصة:* الاختلافات الواضحة في الاتزان الوظيفي للركبة بين المراحل الثلاث والممثل في معايير اختبارات القفز على قدم واحدة تعكس احتمالية وجود فرصة عالية لاختلال الثبات الوظيفي للركبة خلال المرحلة الثالثة (مرحلة ما قبل الحيض) من الدورة الشهرية الأنثوية الطبيعية، وهذا المبدأ يجب الأخذ به ف ي الاعتبار أثناء التخطيط لبرامج التدريب ، المشاركة في اللعب ، أو إعادة التأهيل للرياضيات البالغات .

الكلمات الدالة : الثبات الديناميكى للركبة ، مراحل الدورة الشهرية الأنثوية ، معدل التناسب الأيزوكينيتيكى بين العضلة الخلفية والعضلة الأمامية، اختبارات القفز على قدم واحدة .