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ORIGINAL PAPER

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Anterior knee laxity in young women varies with their menstrual cycle

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Abstract We studied 16 women 21–23 years old with regular menstrual cycles (28±4 days) and no history of knee injury. From their basal body temperatures and the serum concentrations of estradiol and progesterone, the follicular, ovulatory, and luteal phases were delineated. Using a KT-2000 arthrometer, anterior displacement at 89 N and 134 N and anterior terminal stiffness (N/mm) at 134 N were measured two or three times every week over a 4-week period. Eight men 21-23 years old were also measured. In women the anterior displacement at 89 N varied between the follicular and the ovulatory phase and between the follicular and the luteal phase ($P<0.05$) and at 134 N between the follicular and the luteal phase ($P<0.05$). There were no statistical differences in the anterior displacement with time in men, nor in anterior terminal stiffness in either sex. We conclude that anterior cruciate ligament laxity in women might be dependent on the concentrations of hormones.

Résumé Nous avons étudié seize femmes agées de 21 à 23 ans avec des cycles menstruels réguliers (28±4 jours) et sans antécédents de traumatisme du genou. Les phases folliculaire, ovulatoire et lutéale ont été délimitées à partir des températures corporéales basales et des concentrations sériques d'œstradiol et de progestérone. En utilisant un arthrométre KT-2000 le déplacement antérieur sous 89 N et 134 N et la raideur terminale antérieure (N/mm) à 134 N ont été mesurés 2 ou 3 fois chaque semaine sur un période de 4 semaines. Les mesures ont aussi été faites chez huit hommes agés de 21 à 23 ans. Chez les femmes le déplacement antérieur à 89 N a varié entre la phase folliculaire et ovulatoire, et entre la phase folliculaire et lutéale ($p<0,05$) et à 134 N entre la phase folliculaire et lutéale ($p<0,05$). Il n'y avait pas de différences statistiques dans le déplacement antérieur chez les hommes, ni dans la raideur terminale antérieure dans l'un et l'autre sexe. Nous concluons que la laxité du ligament croisé antérieur chez la femme peut être dépendante des concentrations hormonales.

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Introduction

Significant advances in the diagnosis and treatment of anterior cruciate ligament (ACL) injuries have been achieved during the last 2 decades [10, 16]. The ultimate goal nowadays is to define risk factors and to develop effective injury prevention programs. ACL injuries occur through both contact and noncontact mechanisms. Recently, injury of the ACL has been reported to be two to eight times higher in women than in men participating in the same sports. Previous studies have indicated noncontact mechanisms as the reason for ACL tears in women, which make these injuries even more perplexing [1, 2, 4, 7, 8, 12, 20].

Female hormones are considered to be one of the etiological factors in ACL injuries [7, 8]. The present study focuses on the hormonal influences on ACL injuries. Specifically, estrogen has been studied in regard to its effects on human connective tissues. Liu et al. has shown that normal connective tissue from women express hormone receptor transcripts for estrogen and progesterone [11]. Fischer et al. showed that estrogen decreases the total collagen content in both tendons and facias in rats [5]. Furthermore, in ovariectomized rabbits, estrogen supplementation results in a significant reduction in the force necessary to cause ligament failure [17]. These observations suggest that the menstrual cycle and estrogen concentration may play an important role in laxity of the ACL. However, it has yet to be determined whether fluctuations in estrogen levels affect the laxity of ACL in women.

The objective of this study was to determine whether ACL laxity in women changes significantly during their menstrual cycle. In this study we hypothesized that ACL laxity in women was dependent on the menstrual cycle.

Material and methods

Twenty women and eight men were examined. They were all volunteers and understood the objective of our research. None of the women used oral contraceptives. Three women were excluded from the study because they had irregular menstrual cycles and one dropped out because of disease. Sixteen women 21–23 (average 21.6) years old with regular menstrual cycles (28±4 days) and no history of knee injury participated in the study.

Measurements of their knees using a KT-2000 arthrometer were performed two or three times every week over 4 consecutive weeks. All women measured their basal body temperature daily for 4 weeks, and estradiol (E2) and progesterone levels in their blood were measured weekly over this time-period. From their basal body temperatures and the concentrations of E2 and progesterone, the follicular, ovulatory, and luteal phases were delineated. Among the women a total of 342 measurements were made. The follicular phase was represented in 158 measurements, the ovulatory phase in 56 measurements, and the luteal phase in 128 measurements. Eight men 21–23 (average 21.5) years old were also studied. Measurements of their knees using a KT-2000 arthrometer were performed three times a week over a 3-week period. Female hormone levels were not measured in their blood. The three phases of their analysis were defined as the first, second, and third week. A total of 144 measurements were obtained from the men, with 48 measurements made in each of the three phases.

Anterior displacement was evaluated at 89 N and 134 N and anterior terminal stiffness (N/mm) at 134 N over the three phases in women and men respectively. Y. S. performed all measurements.

All data were analyzed statistically by ANOVA followed by Fischer's PLSD for multiple comparisons with a significant level at $P<0.05$.

Results

In women the anterior movements in the follicular phase were 4.7±0.8 mm at 89 N and 6.4±1.0 mm at 134 N. In the ovulatory phase the results were 5.3±0.7 mm at 89 N and 6.8±0.9 mm at 134 N, and in the luteal phase 5.2±0.7 mm at 89 N and 6.9±1.1 mm at 134 N. The differences were statistically significant, both between the follicular phase and the ovulatory phase and between the follicular phase and the luteal phase at 89 N, and between the follicular phase and the luteal phase at 134 N (Fig. 1).

In men the anterior movements through the period did not show any statistical differences. In women the anterior terminal stiffness in the follicular phase was 3.39 ±0.92 N/mm at 134 N, in the ovulatory phase 3.32 ±0.71 N/mm, and in the luteal phase 3.15±0.85 N/mm at 134 N. There were no significant differences in anterior terminal stiffness between the three periods in either women or men.

Discussion

The higher number of women with ACL injuries than men has been attributed to anatomic differences, joint laxity, training techniques, and hormones. The potential role of hormones in predisposing female athletes to ACL injury has been an area of active investigation. Several researchers have determined that female hormones can influence the composition and mechanical properties of the ACL. Karageanes et al. [9] reported an insignificant change in ACL laxity from the follicular to the luteal phases of the menstrual cycle in high school females. We assume that their study's females (14–18 years old) were so young that their menstrual cycles were unstable. Moreover, they did not evaluate the females' hormone concentrations to determine menstrual cycle. We found that their conclusions were different from our results.

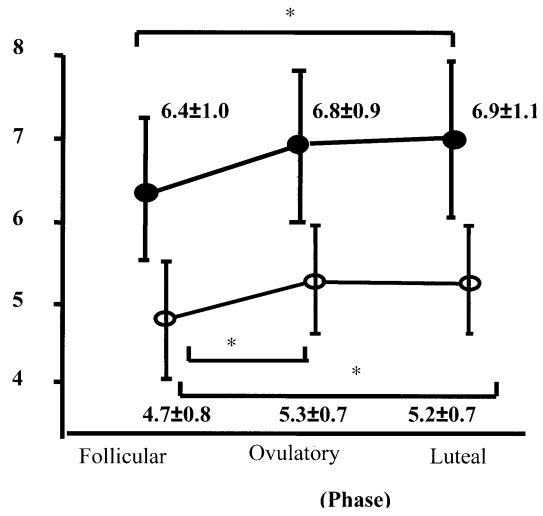

Fig. 1 Anterior movement of the knee in millimeters as measured at 89 N and at 134 N in the different phases (mean ± SD). ○ Anterior movement at 89 N, ● anterior movement at 134 N, * $P<0.05$

Some investigators have attempted to link hormone fluctuations during the menstrual cycle to the rate of ACL injuries [13, 19]. Wojtys et al. [19], in their retrospective study, observed that that there were more injuries of the ACL than expected in the ovulatory phase of the cycle; fewer injuries occurred in the follicular phase. On the other hand, Myklebust et al. [14] found fewer injuries during the mid-cycle estrogen surge (late follicular and ovulatory phases) in a group of Norwegian women's team handball players. These results are contradictory. The present study focused on female hormones as a cause of ACL laxity. We measured knee laxity with a KT-2000 arthrometer. Our results demonstrated a significant difference in the anterior displacement of the knee between the follicular phase and the ovulatory and luteal phases. This observation suggests that anterior displacement of the ACL in women is dependent on the menstrual cycle. Anterior terminal stiffness however, did not differ significantly between the three menstrual phases. There was no statistically significant relation between ACL laxity and the concentrations of female hormones.

We can suggest two possible reasons for these observations. First, anterior terminal stiffness, which potentially would be an important cause of ACL injury, is dependent on the mechanical property of ACL. Female hormones may affect ACL laxity but not the mechanical

property of ACL [6]. Second, women's hormone levels were measured only once a week, which may not be sufficient to monitor concentration fluctuations.

Previous in vivo studies have shown that collagen structure in women changes with fluctuations in hormones [11, 15]. Relaxin is one of the female hormones reported to alter collagen metabolism in humans [3, 18]. Furthermore, the concentration of relaxin is dependent on the menstrual cycle [3]. The current in vivo results support previous in vitro observations. The collagen fibers increase in laxity from the ovulatory phase to the luteal phase, that is, in the period of high relaxin concentrations. However, we do not believe that the increase of ACL laxity fully explains the high injury ratio. It is important to emphasize that a variety of factors are responsible for the high rate of ACL injuries among women.

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