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ORIGINAL ARTICLE

Young Females Exhibit Decreased Coronal Plane Postural Stability Compared to Young Males

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Abstract *Background:* Female athletes are at significantly higher risk of noncontact ACL injury than males, particularly in pivoting sports such as soccer and basketball. Sex-based differences in proprioception and core stability may contribute to this elevated risk. *Questions/Purpose:* This study evaluates a novel method of assessing dynamic stability to test the hypothesis that healthy adolescent controls have sex-based differences in postural stability. *Methods:* Seventy-nine male and 72 female subjects completed three rounds of dynamic postural stability testing. During the assessment, subjects attempted to stabilize their torso and upper body in response to random movements of the platform. The total time a subject lasted on the platform and dynamic motion analysis (DMA) score, a summation of motion in five planes throughout testing, was calculated for each subject. The average score for each subject was included in the analysis. *Results:* Males lasted longer on the platform (98±14 s) than females (94±13 s) (p=0.04). Coronal plane and rotation stability differed significantly between genders (323±126 vs. 365±128, p=0.04) and (318±82 vs. 403±153, p=0.0002), respectively. No statistically significant difference was seen in the other planes of motion. *Conclusions:* Females have less dynamic postural stability than their male counterparts in the coronal plane based on a novel assessment tool. This finding may contribute to better understanding of sex-based differences in rates of injury such as noncontact ACL tears.

Keywords core stability · dynamic stability · male · female · adolescent · ACL

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Level of Evidence: Cohort study, level 2b (prospective)

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Introduction

Female athletes have a significantly higher risk of noncontact ACL injury than their male counterparts [1, 2, 5, 9, 14, 20, 21, 23]. In particular, pivoting sport like soccer and basketball put adolescent females at increased risk [1, 5]. There is significant interest surrounding the role of core stability particularly as it relates to the gender disparity in ACL tears and how instability in different planes may be contribute to injury [17]. For example, coronal plane differences have been associated with valgus collapse and subsequent ligament injury in female athletes [11]. Furthermore, lateral plane displacement of the trunk appears to be a significant predictor of knee injury risk [22].

There has been considerable research exploring factors that contribute to the gender-specific risk of ACL injury and whether preventable measures can be taken to mitigate these risk factors [10, 12, 15]. While a number of ACL injury prevention programs have been shown to decrease the risk of noncontact injuries [10, 12, 15], it can be difficult to measure the direct neuromuscular effect of these programs on individuals. These difficulties stem in part from lack of reproducibility in measuring and quantifying plane-specific dynamic stability.

Recently, a platform has been created as a rehabilitation tool that measures trunk control during dynamic posturography in various planes [6]. The device is called the Proprio 5000. It evaluates trunk control via an ultrasonic sensor on the lumbosacral junction which measures perturbations in the center of mass. The resulting quantitative data measures the end effect of multiple neurological inputs on proprioception and dynamic postural stability. While no "gold standard" has been established for assessing core stability, this new tool correlates with other accepted measurement techniques like the NeuroCom sensory organization test [4]. A study previously used this platform to measure difference in dynamic stability in patients undergoing total hip arthroplasty versus hip resurfacing, suggesting that this technique is useful for assessing alterations in postural stability related to lower extremity pathology [13].

The purpose of the current study is to assess a novel method of assessing dynamic stability to test the hypothesis that dynamic postural stability in a healthy young population differs by sex, both overall and by specific planes of motion. Secondarily, we wanted to assess whether age, BMI, and activity level relate to dynamic stability in this population.

Patients and Methods

This prospective cohort study recruited individuals from local area high schools, colleges, and athletic teams through athletic trainers, coaches, and athletic directors. Exclusion criteria included either prior knee pathology or concomitant articular cartilage or ligamentous injury, contralateral knee pathology, and other general medical conditions affecting proprioception or postural stability. Subjects under age 20 were consented for the study and then scheduled for evaluation by our physical therapist.

Individuals filled out a Marx activity score at the time of their evaluation [16]. Due to limited variability and a ceiling effect in males, individuals were classified as low activity (scores less than 12) versus high activity (scores 12 or more). Their height and weight were recorded, and a body mass index (BMI) was calculated. Individuals were classified as underweight/healthy weight versus overweight/obese using standard weight categories (if 20 years or older) or age- and gender-specific BMI percentiles (if younger than 20 years) according to Centers for Disease Control and Prevention guidelines.

All individuals received the following instructions prior to testing on the multidirectional platform: The purpose of the test is to measure your balance and stability. When the test begins, the platform under your feet will begin to move. Initially, the platform will start slowly and get progressively faster. The platform will also move gradually through a greater range of motion. Keep your upper body and pelvis as still as possible and use your legs to react to the movement.

The multidirectional platform used in this study was the Proprio 5000 (Perry Dynamics, Decatur IL, Fig. 1). The platform moved up to 25° in all directions and can attain a speed of 128° per second. The machine-operated utilizing microprocessor controlled servo actuators. Ultrasonic technology from a transmitter positioned over a subjects' waist measure movements at one fourth second intervals to the nearest 0.004°. Each subject underwent a 2-min test that begins with minimal movement and gradually increases over time. While the movements occurred at random, each 2-min test replicated the same movements. The test ended prematurely if a subject exceeded a 3-in movement in a one fourth of a second or if the sensor exceeds left a 5-in sphere from the starting position. Additionally, the clinician stopped the test if the patient releases the rope, moved their foot position, or if the patient requested to stop the test. Each subject completed three trials on the device, and an average score was used for the analysis.

At the conclusion of the tests, the patient received a dynamic motion analysis (DMA) score. This score measured the total motion in all planes during the test. The more motion a patient demonstrates, the higher the DMA score would be. Scores ranged from 0 (no movement) to 1440 (test stops as soon as it starts). Plane of motion scores were also calculated for six separate movements: lateral, rotation, lateral flexion, up/down, anterior/posterior, and flexion extension. The ability to measure overall stability, as well as plane-specific stability, during dynamic testing is a relatively unique and novel aspect of this approach.

Continuous measurements were compared between groups (i.e., gender, activity category, and weight status category). Data was reported as mean±standard deviation. When required conditions were not satisfied, variables were

Fig. 1. Proprio 5000 as multidirectional platform used in this study.

log- or rank-transformed prior to analysis. Categorical variables were compared between groups by chi-squared test. Multivariable linear regression analysis was performed for each outcome with gender as the independent variable of interest and age in years, weight status category, and activity category as covariates. Due to influence statistics and large residuals, several observations were reweighted prior to regression model fitting. When the required conditions of normality (for t tests) and linearity, normality of residuals, or homoscedasticity (for linear regression) were not satisfied, variables were log- or rank-transformed prior to analysis. At a power level of 0.05, the sample sizes used in this study provide 80% statistical power to detect a medium effect size of 0.46 or larger for between-group differences [7]. The data analysis was generated using SAS software, version 9.3 of the SAS System (SAS Institute Inc., Cary, NC, USA).

Results

Our hypothesis that dynamic postural stability in a healthy young population would differ by sex was partially confirmed in that coronal plane translation (323±126 189 vs. 365±128, p=0.04) and rotational stability (318±82 vs. 403 ±153, p=0.0002) significantly differed (males having more stability than females). However, overall dynamic postural stability and other planes of motion did not differ significantly by sex; although, males did last longer than females on the device during testing (98±14 s vs. 94±13 s, p=0.04) (Table 3).

Our secondary research objective was to assess whether age, BMI, and activity level relate to dynamic stability. Males were taller, heavier, and more likely to be overweight/obese compared to females (see Tables 1 and 2). They were also more active than females. There was less vertical stability in overweight/obese (203±58 vs. 179±48, p=0.01) and more active (192±56 vs. 175±44, p=0.049) individuals (Table 3). Activity level and weight status category were not associated with any other variables.

Multivariable analysis again confirmed the association of patient sex to time and coronal plane stability after adjusting for age, weight status, and activity category (see Table 4).

Discussion

Healthy adolescent females had less dynamic stability in the coronal plane compared to their male counterparts based on a novel assessment tool. No sex-based differences in dynamic stability were found in other planes of motion. Differences in the coronal plane may contribute to the sex-based differences in rates of injury such as noncontact ACL tears. Secondarily, increased activity level and higher BMI was associated with less vertical stability but did not affect stability in other planes of motion.

Table 2 Categorical data on weight status and activity level

Sex	Weight*		Activity level*	
	Under/healthy	Over/obese	High	Low
Male (n=79)	49	30	63	16
Female (n=72)	58	14	32	39

*Statistically significant difference between males and females

Gender differences in plane-specific postural stability assessed by the Proprio 5000 provide novel insight into knee dynamics. During the initial stages of patient testing, the Proprio was shown to correlated with other established measures of postural stability; however, the Proprio diverges from other assessment devices in later stages of testing by increasing the magnitude of plane-specific change. This unique method of testing may provide novel insight into the young active patient population by challenging and differentiating subjects with predisposing pathology who are more able to compensate at lower levels of testing [4]. Additionally, the Proprio 5000 has been previously validated as a method of measuring postural stability in patients with lower extremity pathology [13]. In the present study, 79 male and 72 female healthy adolescents ages 13–20 completed the study using the Proprio 5000.

Previous research has shown correlations between dynamic platform measures of stability and standardized stability tests. Although a relatively novel device, this system has been compared to the NeuroComSOT for evaluation of postural stability in normal young adults [4]. While the initial stages of the tests were similar, there was no correlation between the full duration Proprio dynamic motion analysis score and any of the NeuroCom SOT variables, which include somatosensory ratio, visual ratio, vestibular ratio, and a composite score. These variables are used to assess overall balance and the relative sensory contributions to balance but in a less dynamic testing situation than the Proprio 5000. Differences in the later stages were thought to arise due to differences in the postural demands and corresponding movement strategies between the two tests. The authors concluded that the Proprio 5000 appears to have some merit as a postural control measurement device in healthy subjects and that further research was warranted.

Table 1 Study population demographics

Sex	Age (years)	Height* (cm)	Weight* (kg)	BMI*	Marx activity*
Male (n=79)	16.8±2.0	178±9.5	76±16.5	23.7±4.0	13.4±4.2
Female (n=72)	17.1±2.4	165±8.6	61±12.5	22.2±3.8	9.9±5.0
p Value	0.33	<0.0001	<0.0001	0.003	<0.0001

*Statistically significant difference between males and females

Table 3 Sex-based comparison of dynamic stability in healthy subjects

Sex	Time* (s)	DMA	A/P	Lateral translation*	Up/down	Flex/ext	Lateral flexion*	Rotation
Male (n=79)	98±14	505±139	279±81	323±126	190±55	543±148	318±82	489±149
Female (n=72)	94±13	536±125	291±69	365±128	181±49	507±152	403±153	517±171
p Value	0.04	0.15	0.32	0.04	0.33	0.14	0.0002	0.29

DMA dynamic motion analysis score, *A*/P anterior/posterior, *Flex*/*ext* flexion/extension

Table 4 Multivariable association of rotation outcomes

	Age (year), calculated		Weight status category (0=under/healthy weight, 1=overweight/obese)		Activity category (0=low activity, 1=high activity)		Gender (0=female, 1=male)		Overall model	
	Parameter estimate (SE)	p Value	Parameter estimate (SE)	p Value	Parameter estimate (SE)	p Value	Parameter estimate (SE)	p Value	p Value	Adjusted R^2
Time (s)	0.55 (0.52)	0.29	−3.1 (2.55)	0.23	0.93 (2.45)	0.70	5.8 (2.42)	0.02	p=0.10	R^2=0.03
DMA	−2.3 (4.81)	0.64	35 (23.87)	0.15	−15 (23.04)	0.51	−42 (22.63)	0.07	p=0.18	R^2=0.02
A/P	−6.3 (2.67)	0.02	13 (13.21)	0.31	−24 (12.64)	0.06	−12 (12.47)	0.33	p=0.04	R^2=0.04
Lat.	0.86 (4.63)	0.85	23 (22.95)	0.32	−7.4 (22.10)	0.74	−52 (21.77)	0.02	p=0.10	R^2=0.03
Up/down*	−0.01 (0.01)	0.53	0.14 (0.05)	0.003	0.07 (0.04)	0.11	−0.02 (0.04)	0.72	p=0.01	R^2=0.06
Flex/ext	3.8 (5.69)	0.50	−24 (28.37)	0.40	19 (27.08)	0.49	44 (26.74)	0.10	p=0.33	R^2=0.005
Lat flex*	0.02 (0.01)	0.17	−0.04 (0.06)	0.44	0.10 (0.05)	0.08	−0.21 (0.05)	0.0002	p=0.0008	R^2=0.10
Rotation*	0.004 (0.01)	0.74	0.05 (0.05)	0.34	0.01 (0.05)	0.88	−0.06 (0.05)	0.27	p=0.70	R^2=−0.01

For each outcome, a multivariable regression model was performed with gender as the independent variable and the following covariates: age, weight status category, and activity category. These models determine if rotation is similar for males and females, after adjusting for the covariates

SE standard error

*Data log-transformed prior to analysis

Another recent study used this system to assess proprioception in patients undergoing hip surgery [13]. Superior-inferior and medial-lateral translation measurements made by the Proprio 5000 have been correlated with measurements from an eight camera motion analysis system and an ultrasonic sensor attached to the lower back [6]. There is also evidence that measuring trunk movements with the Proprio 5000 is a better evaluation of dynamic postural stability than measuring lower leg movements [1]. Nevertheless, further investigation is needed to fully validate this machine and novel application for assessing postural stability. Ultimately, these novel systems may be utilized to determine gender-based differences in core stability and potentially assess risk of lower extremity injury [11].

Other limitations of the current study include the high level of activity in this cohort, with a median Marx activity level of 16 for the males and 11 for the females. Activity level may be more relevant when less active individuals are included, although adolescents are likely to be among the most active individuals in society. Furthermore, the definitions of overweight and obese for body type do not always apply to athletes who often have increased lean body mass.

The lack of injury data is another significant limitation. However, the study was not designed to assess the relationship between dynamic stability and injury risk but rather to identify gender-based differences in healthy adolescents. Given previously published evidence supporting the role of coronal stability in ligament injury risk [9, 17, 22], our findings suggest that these gender-based differences likely contribute to the increased risk of ACL injury in female athletes.

The importance of the coronal plane in gender differences of stability and ACL injury risk has come under increasing scrutiny [14]. Hewett et al. [9] demonstrated that the coronal plane is associated with valgus collapse and subsequent ligament injury in a cohort of 205 female soccer, basketball, and volleyball athletes. Zazulak et al. [22] looked at 277 collegiate athletes to assess the relationship of neuromuscular control of the trunk to knee injury risk. Lateral displacement of the trunk was the single best predictor of knee ligament injury in these athletes. In a video-based study, noncontact ACL injuries were associated with a lateral shift of the trunk over the injured limb in females but not males [10]. Adolescent females have greater knee abduction angle and with the foot further from midline opposite the direction of trunk lean experience greater internal rotation loads. The hip external rotators may also be important as weakness and/or poor neuromuscular control increase the risk of lower extremity injury [13]. Females with strong hip external rotators have been shown to have lower peak vertical ground reactive force and external knee flexor moment during single-leg drop landings [12]. In the same study, the females with weak hip external rotators had greater external knee adduction moment, net knee anterior shear joint reaction force, and a greater hip external adduction moment during the same task. These findings suggest that hip external rotation strength also likely plays a role in ACL injury risk.

In our study, coronal stability is likely related to hip external rotation strength which may be one of the underlying causes of the gender discrepancy in this plane. Female soccer players may be particularly susceptible to deficits in the coronal plane. Hewett et al. [8] found that female soccer players land with significantly greater hip adduction angles and external hip adduction moments compared to male soccer players. Female soccer players have been shown to have weaker hip abductors than their male counterparts [4]. Furthermore, female soccer players have been shown to kick with less activation of their hip abductors than males, resulting in greater collapse of the hip [3].

Unfortunately, coronal imbalances may be among the most difficult to correct. Paterno et al. [18] assessed the effect of a 6-week neuromuscular training program on the single limb postural stability of 41 healthy high school female athletes. While the athletes demonstrated significant improvements in total stability and sagittal stability, they did not improve their coronal stability. The authors called for further investigation into how total, sagittal, and coronal stability related to risk for ACL injury. Conversely, Pollard et al. [19] measured the effect of in-season neuromuscular training on 18 female high school soccer players and found changes in the hip, with less internal rotation and greater abduction, but not the knee during a drop landing task. The Proprio may be a useful tool for assessing the impact of prevention programs on dynamic stability and, ultimately, injury risk [10].

The implications of less vertical stability in patients with a higher BMI and greater activity level are less clear. With a higher BMI, it is plausible that it is more difficult to keep the center of gravity stable, but it is not obvious why this would manifest in the vertical plane and not in other planes of motion. Less vertical stability with greater activity level appears counterintuitive and raises the possibility that such an adaptation might not necessarily be harmful if it minimizes displacement and rotation in other planes. More research is needed to confirm this finding and assess its importance.

Disclosures

Conflict of Interest: Robert H. Brophy, MD, Jonathon R. Staples, MD, John Motley, PT, Ryan Blalock, MD, Karen Steger-May, MA and Mark Halstead, MD have declared that they have no conflict of interest.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was obtained from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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