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Dynamic Valgus Alignment and Functional Strength in Males and Females During Maturation

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Context: Sex differences in dynamic measures have been established in physically mature populations. Gaining information on maturation's effect on dynamic performance measures implicated in injury risk may enable us to better design injury prevention programs.

Objective: To examine sex differences in dynamic valgus alignment and triple-hop distance measures across maturational stages in males and females. A secondary purpose was to determine if a field test of strength and power predicts dynamic valgus alignment.

Design: Cross-sectional study.

Setting: Laboratory.

Patients or Other Participants: 157 young athletes (78 females, 79 males) aged 9 to 18 years.

Intervention(s): Subjects performed drop-jump landings and single-leg triple-hop tests as part of a broader injury screening.

Main Outcome Measure(s): Maturational status was ascertained from self-report questionnaires and grouped according to Tanner stages 1 and 2 (MatGrp1), 3 and 4 (MatGrp2), and 5 (MatGrp3). Frontal-plane knee valgus displacement, which served as a measure of dynamic valgus alignment, and single-leg triple-hop distance were assessed.

Results: Males demonstrated less dynamic valgus alignment during drop jumps in the latter maturational stages (MatGrp1 = 13.1° ± 8.7°, MatGrp2 = 9.0° ± 6.2°, MatGrp3 = 9.2° ± 9.4°), whereas females increased dynamic valgus alignment throughout maturation (MatGrp1 = 11.5° ± 6.9°, MatGrp2 = 12.8° ± 8.8°, MatGrp3 = 15.5° ± 8.7°). Thus, in the more mature groups, males had less dynamic valgus alignment than females. Both males (MatGrp1 = 393.5 ± 63.7 cm, MatGrp2 = 491.8 ± 95.1 cm, MatGrp3 = 559.3 ± 76.3 cm) and females (MatGrp1 = 360.3 ± 37.1 cm, MatGrp2 = 380.1 ± 44.3 cm, MatGrp3 = 440.0 ± 66.2 cm) increased triple-hop distance, but males increased more. Within each subgroup of MatGrp and sex, triple-hop distance had no predictive ability for dynamic malalignment.

Conclusions: When dynamic valgus alignment and strength were assessed, sex and maturational status displayed an interaction. However, functional strength did not predict degree of dynamic valgus alignment.

Key Words: triple-hop test, knee valgus, sex differences

Key Points

- With maturation, males demonstrated less dynamic valgus alignment during a drop jump and females demonstrated more valgus alignment.
- Although both males and females improved their performance in the triple-hop test as they matured, males showed greater improvement.
- The triple-hop test did not predict dynamic valgus alignment by sex or level of maturation.

Musculoskeletal injury risk is reported to increase with age[1–4] and physical maturation status.[5] In a recent review across sports, adolescents (those older than 13 years) were at a consistently increased risk of injury compared with younger children.[6] This risk appears to coincide with physical maturation, because Michaud et al[5] reported that Tanner stages 4 and 5 were associated with an increased occurrence of sport injuries. With authors[6] of a comprehensive literature review reporting that adolescents are consistently at an increased risk of injury with respect to a younger population, we need to focus on the maturing youth population to better understand potential relevant risk factors for injury. Specifically, functional performance changes that occur in males and females as part of the maturation process should be considered further, because young females have a greater risk of straining or spraining the knee and ankle than young males.[7]

Valgus alignments of the lower limb have been associated with injuries to the knee.[8–14] Valgus alignment is an often-reported dynamic alignment measure that is commonly associated with the anterior cruciate ligament (ACL) injury mechanism.[15,16] Dynamic valgus alignment has been described as a bodily position in which the knee collapses medially from excessive valgus or internal-external rotation or both.[17] In a study of 2-dimensional video footage of actual injuries, valgus collapse was described as medial knee collapse, in what appeared to be a combination of hip internal rotation, knee valgus, and external rotation of the tibia.[17] In this study of 39 ACL injuries during high school, college, and professional basketball games, females had a 5.3 times higher relative risk of sustaining a valgus collapse injury mechanism than did males.[17]

Previous investigators[18] have studied the effects of age or maturation and sex on dynamic valgus alignment (as

Table 1. Participants' Age, Height, and Mass by Sex and Maturational Group

		Females		Males	
		Mean ± SD	Range	Mean ± SD	Range
Age, y	MatGrp1	10.9 ± 1.4	9–14	11.2 ± 1.2	9–14
	MatGrp2	13.5 ± 1.6	12–18	14.1 ± 1.6	12–16
	MatGrp3	17.6 ± 1.0	14–18	17.2 ± 1.3	13–18
Height, cm	MatGrp1	154.0 ± 31.5	104.9–176.5	146.1 ± 7.4	132.1–161.3
	MatGrp2	159.8 ± 8.9	125.0–163.0	165.4 ± 11.6	143.7–188.6
	MatGrp3	167.3 ± 6.8	153.7–180.3	176.2 ± 8.9	162.6–198.1
Mass, kg	MatGrp1	40.4 ± 10.2	25.0–67.1	37.2 ± 8.1	28.0–58.0
	MatGrp2	50.2 ± 8.7	37.7–72.1	56.7 ± 12.0	36.9–81.4
	MatGrp3	64.9 ± 8.2	52.0–85.3	75.9 ± 13.3	55.8–107.3

Abbreviations: MatGrp, maturational group; MatGrp 1, Tanner stages 1 and 2; MatGrp2, Tanner stages 3 and 4; MatGrp3, Tanner stage 5.

measured by minimum interknee distance) during a drop-jump test in athletes 9 to 17 years old. They reported no age or sex effects in interknee distance during a drop-jump test. Conversely, Hewett et al[19] reported that total coronal-plane medial knee displacement increased in females but not in males during the later stages of maturation. The authors hypothesized that decreased neuromuscular control of the knee in females after puberty may explain why they appear to be more predisposed to acute ACL injury than do males. The demonstrated lack of a "neuromuscular spurt" in females has been suggested as a contributing factor to the female bias in ACL injury.[20] As males transitioned from Tanner stages 2 or 3 to Tanner stages 4 or 5, this neuromuscular spurt was demonstrated by increased vertical jump height and increased ability to attenuate landing force.[20] This finding suggests that a field test of strength and power may be associated with frontal-plane knee control; however, no predictive or corollary analyses were performed to ascertain whether the dynamic limb alignment measures were correlated with the changes in functional strength that occur during maturation.

Greater single-leg triple-hop distance (an easily performed field test) was a strong predictor of greater vertical jump height (explaining 69% of the variance) and greater isokinetic peak knee torque (explaining between 49% and 58% of the variance).[21] In combination with the possibility that increased vertical jump may reflect decreased medial knee displacement,[20] single-leg triple-hop performance may be related to the amount of frontal-plane knee valgus. Our purpose was to use a cross-sectional design to examine sex differences in functional valgus collapse and a field test of strength and power across stages of maturation. A secondary purpose was to determine if the field test of strength and power predicted the degree of functional valgus collapse within each sex and maturational group.

METHODS

Participants

A cohort of 157 young athletes, aged 9 to 18 years (78 females: height = 155.4 ± 21.8 cm, mass = 57.83 ± 27.8 kg, age = 14.0 ± 3.0 years; 79 males: height = 162.9 ± 15.1 cm, mass = 56.6 ± 18.7 kg, age = 14.1 ± 2.76 years), volunteered to participate in this study (Table 1). The athletes were recruited from local youth and collegiate sport leagues, the Young Men's Christian Association, and church youth groups within the local metropolitan area. Most participants were recruited from sport-specific programs, with 75% of the volunteers involved in 1 or 2 regular sporting activities (at least 1 day per week) and 25% involved in 3 or more organized sport activities. Each participant provided informed consent or assent, as required by the university's institutional review board, which approved the study. For those volunteers younger than age 18, parental or guardian consent also was obtained.

Procedures

We collected data over 2 years during comprehensive, multistation examinations assessing lower limb anatomical measures, as well as dynamic valgus alignment and functional performance measures. Each participant's sex, age, height, and mass were recorded. Other demographic information also was collected, including history of sport participation, number and types of sports played on a regular basis, and limb dominance. Specific to the current study, dynamic valgus alignment was assessed during a drop-jump screening test,[15] functional performance was assessed using a triple hop for distance,[21] and stage of maturation was assessed using a modified Tanner staging questionnaire.[22]

Maturational Status. Level of maturation was assessed using a validated, self-administered questionnaire to identify adolescent development stage[22] based on the Tanner 5 stages of maturity.[23] Drawings made from Tanner's photographs illustrating the 5 stages of development for male genitalia and pubic hair were provided to male participants; the 5 stages of development for female breasts and pubic hair were provided to female participants. Explanatory information accompanied the drawings. Minor modifications from the original questionnaire[22] were to reformat the text layout to improve readability and to have the participant only choose the 1 drawing that he or she most closely resembled (instead of ranking the first and second). All other drawings and text were original. This instrument has been found to be both valid and reliable in children ages 8 to 18 years.[24] Participants completed the sex-appropriate questionnaire in a private office with the door closed, and they were instructed to insert their assessment through a small slot in a box once completed. All participants were assured that code numbers would be used to analyze their data and that their names would not be linked to their answers. From these data, each male or female volunteer was placed into 1 of 3 maturational groups: MatGrp1 (n = 25 females, 23

Table 2. Two-Dimensional Valgus Knee Displacement and Single-Leg Triple-Hop Distance by Sex, Side, and Maturational Group

		Females		Males	
		Mean ± SD		Mean ± SD	
		Left Side	Right Side	Left Side	Right Side
Valgus knee displacement, °	MatGrp1	10.0 ± 6.4	12.9 ± 7.4	14.3 ± 9.3	11.9 ± 8.2
	MatGrp2	12.2 ± 8.1	13.5 ± 9.6	8.9 ± 5.7	9.1 ± 6.7
	MatGrp3	15.9 ± 9.2	15.1 ± 8.4	8.8 ± 7.9	9.6 ± 10.9
Single-leg triple-hop distance, cm	MatGrp1	354.6 ± 33.3	375.2 ± 40.9	392.0 ± 68.3	394.1 ± 60.3
	MatGrp2	375.2 ± 40.9	385.3 ± 48.8	495.0 ± 99.1	488.6 ± 3.1
	MatGrp3	443.2 ± 66.1	436.7 ± 67.6	556.9 ± 74.2	561.6 ± 79.9

Abbreviations: MatGrp, maturational group; MatGrp 1, Tanner stages 1 and 2; MatGrp2, Tanner stages 3 and 4; MatGrp3, Tanner stage 5.

males) consisted of stages 1 and 2, MatGrp2 (n = 28 females, 33 males) consisted of stages 3 and 4, and MatGrp3 (n = 25 females, 23 males) consisted of stage 5. The rationale for collapsing stages 1 and 2 and stages 3 and 4 was to achieve a more balanced sample size for comparisons.

Drop-Jump Screening Test. A drop box 0.30 m high was placed perpendicular to a video camera with an effective sampling rate of 60 Hz; the video camera was leveled and positioned 0.6 m above the ground on a tripod at an approximate distance of 4.0 m directly in front of the leading edge of the drop box. The video camera was connected to a laptop computer containing Datapac 2K2 software (Run Technologies, Mission Viejo, CA). A spotlight was placed directly behind and just above the video camera, and a black curtain was placed behind the drop box. Using athletic tape, an *X* was marked on the laboratory floor, approximately 0.2 m in front of the drop box. The drop box was then moved forward 0.2 m, and the field of interest (x and y coordinates) was calibrated using the software. After calibration, the drop box was moved back to its original position, and the investigator prepared the participant for data collection.

Volunteers were instructed to wear low-cut court shoes and dark, tight-fitting clothing. Using double-sided tape and adhesive spray, the investigator attached six 1.27-cm reflective markers to the greater trochanter, center of the patella, and lateral malleolus of each leg. Participants were given the following verbal instructions to complete the drop-jump task: "(1) Stand on top of the drop box, facing the camera with your feet shoulder-width apart, toes just off the edge, and hands at chest level. (2) Drop directly down off the box toward the *X* on the floor, land equally on both feet, and immediately perform a maximum vertical jump, raising both hands as if you were jumping for a basketball rebound." Before data collection, the investigator demonstrated the drop-jump task, and the volunteers were encouraged to take 1 to 3 practice repetitions. For each participant, 3 trials of data were collected on 1 continuous video file. Error trials were ascertained visually by a lowering of the center of mass before dropping off the box, not landing equally on both feet, a blocked or dislodged marker, an inability to land on the *X*, or a failure to jump straight up and down on the second jump.

After data collection, we analyzed the video data using the Datapac 2K2 software. For each of the 3 drop jumps, the hip, knee, and ankle markers were digitized from the point of initial contact (as visually determined from frame-by-frame advancement) through the "ground off" phase of the jump from the ground. Frontal-plane, 2-dimensional valgus angles were then calculated throughout this duration as the angle formed between the hip-to-knee segment and the knee-to-ankle segment. Valgus directions were denoted as positive. *Dynamic valgus alignment* was defined as the planar valgus displacement from average initial contact to the average peak valgus angle for each trial. Such obtained angles do not represent true 3-dimensional bony knee motion,[15] and such positioning is likely the result of knee flexion angle along with hip internal rotation, knee valgus, and external rotation of the tibia.[17] Although previous authors[15,16,18,23] have normalized linear knee separation distance during a drop-jump task, we used a measure of angular position that does not require normalization techniques.

Triple Hop for Distance. A subset of the population completed single-leg triple-hop testing (n = 116; MatGrp1: n = 15 females, 19 males; MatGrp2: n = 14 females, 23 males; MatGrp3: n = 22 females, 23 males). A 10-m tape measure was secured to the laboratory floor. Testing was completed on both right and left legs with a counterbalanced design. Four participants were tested unilaterally due to preexisting conditions. Volunteers began the protocol by standing on the designated testing leg with their toes placed on the starting line. They were then instructed to perform 3 maximal single-leg forward hops using the same leg. Each participant completed this procedure 3 times on each limb, alternating limbs for each trial, and attempted to hop as far as possible. Before testing, 1 to 3 practice trials were permitted. The investigator measured the distance hopped from the starting line to the point where the heel hit on the completion of the third and final hop. We decided not to normalize triple-hop distance by any anthropometric measure, because functional movement tests have been suggested to have little relation to body size.[25,26] The average of 3 trials was used for analyses.

Statistical Analyses. Descriptive statistics of valgus displacement and triple-hop distance (mean ± SD) were computed by MatGrp and sex (Table 2). Using separate 2 (sex) × 2 (side) × 3 (MatGrp) factorial analysis of variance models, we examined differences for the dependent variables of valgus displacement and triple-hop distance between sexes and among maturational groups. Side was included in the model to test for any systematic differences between the right and left legs. Tukey post hoc tests were used to test the significant F values. A stepwise linear regression examined the relationship of triple-hop distance (predictor variable) and valgus displacement (dependent variable) within each sex and each maturation group. An α level of .05 was set for all analyses.

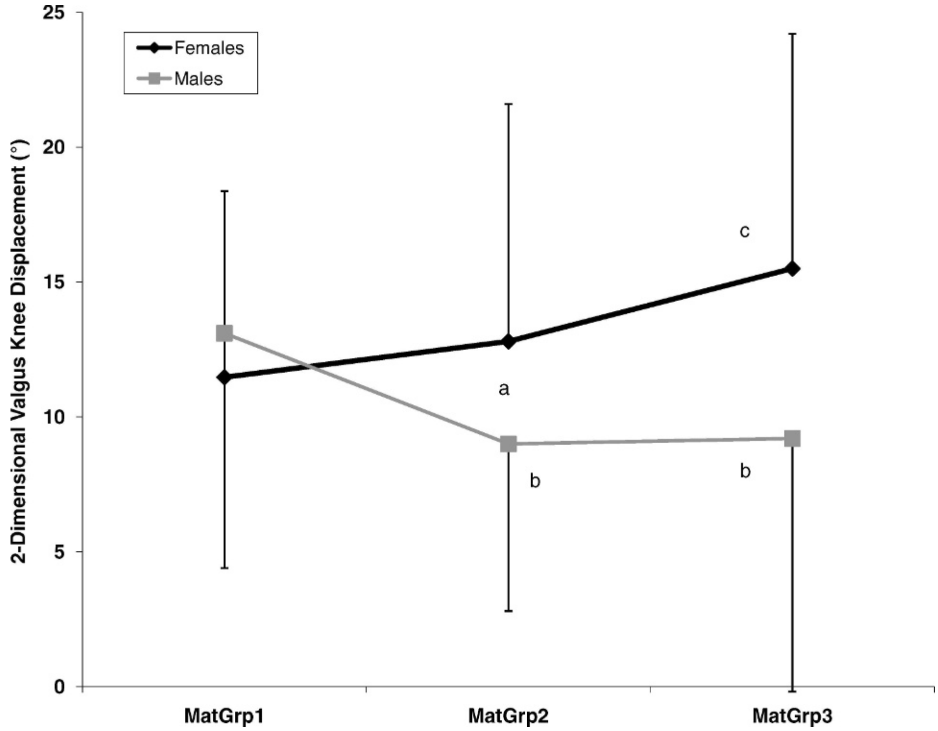

Figure 1. Two-dimensional valgus knee displacement. An interaction of sex and MatGrp is demonstrated ($P = .003$). [a] Males in MatGrp2 and MatGrp3 < females in MatGrp2 and MatGrp3; [b] males in MatGrp2 and MatGrp3 < males in MatGrp1; [c] females in MatGrp3 > females in MatGrp1. MatGrp indicates maturational group; MatGrp 1, Tanner stages 1 and 2; MatGrp2, Tanner stages 3 and 4; MatGrp3, Tanner stage 5.

RESULTS

We found an interaction between sex and MatGrp for valgus displacement ($F_{2,302} = 5.923$, $P = .003$). Although males and females in MatGrp1 did not differ, males had less functional valgus collapse than females in MatGrp2 (males = 9.0° ± 6.2°, females = 12.8° ± 8.8°, effect size = 0.45) and MatGrp3 (males = 9.2° ± 9.4°, females = 15.5° ± 8.7°, effect size = 0.75) (Table 2). Additionally, males decreased their valgus displacement from MatGrp1 to MatGrp3 (13.1° ± 8.7° versus 9.2° ± 9.4°, effect size = 0.46), whereas females demonstrated greater valgus displacement from MatGrp1 to MatGrp3 (11.5° ± 6.9° versus 15.5° ± 8.7°, effect size = 0.48; Figure 1). Side was not a factor, either as a main effect or as part of an interaction.

The triple-hop distance reflected an interaction of sex and MatGrp ($F_{2,216} = 7.781$, $P = .001$). Although results for females and males in MatGrp1 did not differ, males had a greater triple-hop distance than females in MatGrp2 (males = 491.8 ± 95.1 cm, females = 380.1 ± 44.3 cm, effect size = 1.21) and MatGrp3 (males = 559.3 ± 76.3 cm, females = 440.0 ± 66.2 cm, effect size = 1.19) (Table 2). Additionally, males increased triple-hop distance from MatGrp1 (393.5 ± 63.7 cm) to MatGrp2 (491.8 ± 95.1 cm, effect size = 0.99) and MatGrp3 (559.3 ± 76.3 cm, effect size = 1.66), whereas females increased triple-hop distance from MatGrp1 (360.3 ± 37.1 cm) to MatGrp3 (440.0 ± 66.2 cm, effect size = 0.80) (Figure 2). Side was not a significant factor, either as a main effect or as part of an interaction.

Linear regression revealed that triple-hop distance did not predict dynamic valgus alignment within MatGrp or sex (R^2 range =.005 to .084). Only males in MatGrp2 trended toward statistical significance in triple-hop distance predictive capability ($R^2 = .084$, $P = .051$).

DISCUSSION

Our primary finding is that males demonstrated less dynamic valgus alignment during a functional task in the latter stages of maturation, whereas females demonstrated increased dynamic valgus alignment throughout maturation. With maturation, both males and females increased their performance on a functional strength task; however, males increased more than females. Interestingly, triple-hop distance did not predict dynamic valgus alignment within each sex or level of maturation.

It is important to reiterate that the degree of dynamic valgus alignment reported is simply a frontal-plane measure of integrated lower extremity function and not a measure of arthrokinematic frontal-plane knee rotation. Although the shortcomings of planar analyses have been discussed elsewhere,[27] it has been suggested[15,16] as helpful in determining global lower extremity alignment. Some previous authors[18] have reported that no age or sex effects existed in interknee distance during a drop-jump test, but others[19] have noted that total coronal-plane medial knee displacement increased in females but not in males during the later stages of maturation. Direct comparisons with these previous works are complicated by the fact that we calculated a change in 2-dimensional frontal-plane knee angle, whereas the others used absolute measures of interknee distance[18] and total medial knee displacement.[19]

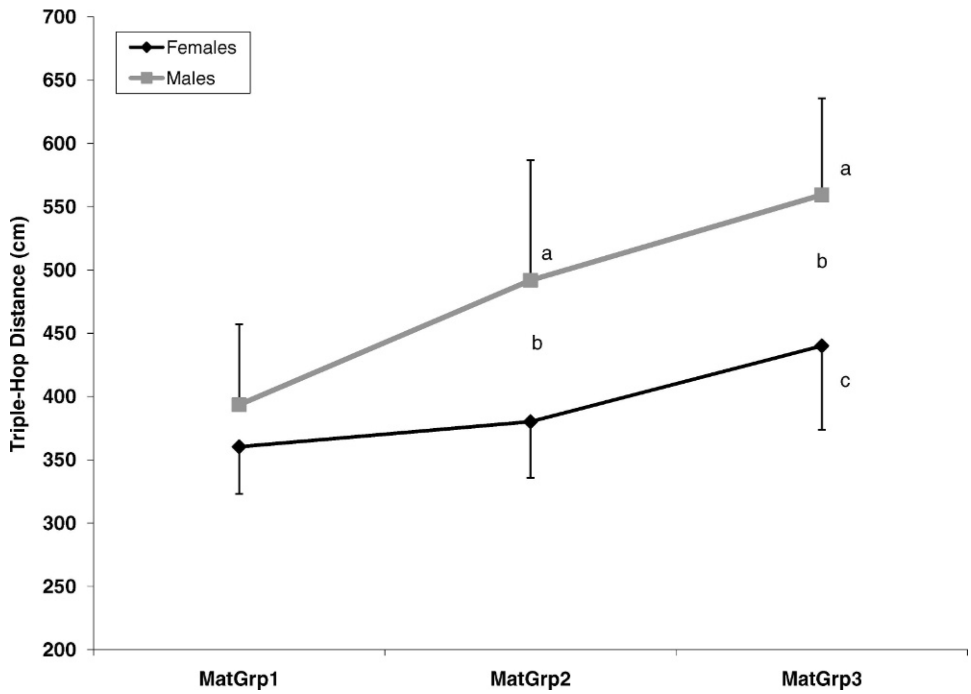

Figure 2. Triple-hop distance. An interaction of sex and MatGrp is demonstrated ($P = .001$). [a] Males in MatGrp2 and MatGrp3 > males in MatGrp1; [b] Males in MatGrp2 and MatGrp3 > females in MatGrp2 and MatGrp3; [c] females in MatGrp3 > females in MatGrp1. MatGrp indicates maturational group; MatGrp 1, Tanner stages 1 and 2; MatGrp2, Tanner stages 3 and 4; MatGrp3, Tanner stage 5.

For the triple-hop distance, we found a sex difference only in the more skeletally mature groups. Additionally, males but not females increased performance from MatGrp1 to MatGrp2, suggesting a more rapid gain in functional strength in males. We have been unable to directly compare our triple-hop data with those of previous authors. With regard to jumping task performance in 13- to 30-year-old males and females, squat jump height in the 13-year-old group did not differ by sex, but a sex difference was evident in the older age groups.[28] When participants were grouped by maturational stage, males increased vertical jump height across maturational stages, but females did not.[29] Although not directly reported by the authors, the data would suggest no difference between the sexes at the early stage of maturation.[29] Similarly, no differences in isokinetic strength measures have been reported in 9- and 10-year-old boys and girls.[18] Throughout the literature, there appears to be a sex- and maturational stage–dependent effect on strength and power measures, with males consistently increasing strength and power measures more than females.

Previous authors[19,20] have supported the concept that the observed maturation-related musculoskeletal changes are associated with reduced neuromuscular knee control in female athletes. Given that males had less dynamic valgus alignment and greater triple-hop distance in MatGrp2 and MatGrp3 than females had, functional strength would seem to play an important role in explaining the amount of dynamic valgus alignment. However, within each sex and maturation group subset, triple-hop distance did not predict dynamic malalignment. This dynamic valgus alignment is likely to be related to a combination of factors that include strength, coordination, skill, anatomical alignment, and underlying arthrokinematic function.

Similar to our results of increasing triple-hop distance as maturation progresses, previous authors[19,20,29,30] have observed greater improvements in functional strength expression in boys than in girls during maturation. Although no sex differences in lower extremity muscle strength are evident when equal amounts of muscle are compared,[31] sex differences in body composition that emerge with maturation[32] indicate that maturing females have less muscle mass to move and control each unit of total body weight during sport activities than their male counterparts. The demonstrated lack of a ‘‘neuromuscular spurt’’ in females during maturation may contribute to the female bias in ACL injury.[20] Maturing females have smaller overall gains in thigh strength (27% in hamstrings, 44% in quadriceps) and an increase in quadriceps-to-hamstrings strength ratios compared with maturing males, who exhibit much greater and more balanced strength gains (179% in hamstrings, 148% in quadriceps).[30] Furthermore, Hewett et al[19,20] observed that boys demonstrated better neuromuscular control of the knee, greater vertical jump height, and smaller landing forces from early to late pubertal stages, whereas girls demonstrated decreased neuromuscular knee control and no change in vertical jump height or landing forces. The authors concluded that the lack of neuromuscular spurt and reduced knee control in females may be related to an increased risk of knee injury in females in the late pubertal stages and may be due, in part, to changes in contraction patterns of the hip adductors and abductors during physical maturation.[19] This idea of frontal-plane control changes may help to explain why performance on a sagittal-plane–dominated task, such as the triple hop, did not predict the degree of dynamic malalignment. Dynamic malalignment does not appear to be solely a function of flexor-extensor strength.

Several limitations of this study should be addressed. Our findings are based on a cross-sectional design using a relatively small sample size (n = 157). To acquire a more balanced distribution of sex and maturational stages, this sample size required us to transform the 5 Tanner maturational stages into 3 groups.[33] Also, participants who reported involvement in multiple sports limited our ability to categorize the level of physical activity and sport across all subgroups. We cannot be certain that the type and volume of activity were consistent among subgroups. Future authors studying larger numbers in a prospective, longitudinal design will provide a more descriptive view of the effect of maturation on dynamic valgus alignment and strength. Additionally, how the 2-dimensional planar analyses we performed relate to actual 3-dimensional arthrokinematic function is unknown.

CONCLUSIONS

Males in the latter stages of maturation demonstrated less dynamic valgus alignment during a drop jump, whereas females demonstrated increased malalignment throughout maturation. Although both males and females increased their performance in triple-hop distance with maturation, males increased by a greater amount. When we accounted for sex and maturational status, triple-hop distance did not predict dynamic malalignment. Further research is needed to determine the actual joint biomechanics when a large amount of 2-dimensional dynamic valgus alignment is present as well as the specific contributing factors causing such valgus alignment. Additionally, developing clinical tasks that better assess frontal-plane stabilization would give clinicians another tool to predict valgus collapse. These data may help us to better design focused rehabilitation interventions in physically maturing populations.

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