Original Article

Correlation between dynamic knee valgus and quadriceps activation time in female athletes

NICOLA MAROTTA MD¹, ANDREA DEMECO MD², LUCREZIA MOGGIO MD³, LORENZO ISABELLO MD⁴, TERESA IONA PHD⁵, ANTONIO AMMENDOLIA PROF⁶

¹Department of Surgical and Medical Sciences, University of Catanzaro "Magna Graecia" ITALY

Published online: September 30, 2020

(Accepted for publication: September 22, 2020)

DOI:10.7752/jpes.2020.05342

Abstract:

Objectives: The risk for female athletes suffering an anterior cruciate ligament injury is 3.5 times more than males. The high rate of anterior cruciate ligament injuries in females compared to males appears to be due to worse neuromuscular control strategies. The unbalanced ratio between the medial and lateral quadriceps and the dynamic valgus knee contribute to increasing the risk of the lesion to the anterior cruciate ligament. This study aims to evaluate the correlation between the increased dynamic valgus knee and the reduction of the mediolateral quadriceps ratio in recruitment and timing during a movement that puts the anterior cruciate ligament under stress. **Methods:** We enrolled sixty athletes (30 males and 30 females): professional dancers, soccer, and volleyball players. To put stress on the anterior cruciate, the athlete falls with one leg from a 32 cm platform. Four surface EMG probes determined the rectus femoris (RF), vastus medialis (VM), semitendinosus (ST), and biceps femoris (BF) activation time. An inertial motion sensor connected to the probes can quantify the pre-activation time of the muscles. An open-source video post-production software (Kinovea) defined the angle dynamic valgus knee. **Results:** female athletes showed a delayed mediolateral quadriceps activation and wider dynamic valgus knee angles compared to males. Pearson's r test ($t = 9.8$, $df = 58$, $p < 0.05$) showed a significant correlation of 0.79. **Conclusions:** These results seem to suggest a linear correlation between late activation of the vastus medialis recorded in women and the dynamic angles of the valgus. These findings confirm the need for training programs that increase neuromuscular control strategies.

KeyWords: ACL injury, vastus medialis, kinovea, neuromuscular training,

Introduction

The incidence of anterior cruciate ligament (ACL) tear is 2.8-3.5 times greater in women than in the man [Ireland, 2002] [Brophy et al., 2010; Sutton & Bullock, 2013]. The ACL injuries commonly occur in non-contact situations during direction changes, cutting maneuvers, or during landing after jump [Boden et al., 2000]. But so far, few prospective studies have investigated biomechanical risk factors of ACL injury [Leppänen et al., 2017]. Plausible explanations for the higher rate of ACL injury in females compared with males have also been proposed, that is, worse neuromuscular control strategies cutting movement and lower hamstring to quadriceps torque ratios [Di Stefano et al., 2015; Ryman Augustsson & Ageberg, 2017]. Females showed an increase in dynamic valgus misalignment during ACL stress activities [Schmitz et al., 2009]. Hewett demonstrated that an increase in valgus movements and stress valgus moments in the knee joint during the impact phase of the jump-landing pattern are predictors of potential ACL injury in women [Timothy E. Hewett et al., 2005]. A drop-jump test can indicate an athlete's ability to control the axial alignment of the lower limb on the coronal plane [Noyes et al., 2005]. The altered neuromuscular timing and recruitment can lead to the aforementioned dynamic stress in the lower limb valgus observed in women [T. E. Hewett et al., 2005]. Rozzi et al. reported that female athletes show four times greater activation of their hamstring muscles than males during landing [Rozzi et al., 1999]. The combination of surface electromyography (sEMG) with inertial sensor showed a neuro-motor imbalance of late activation of the vastus medialis in females compared to males during a maneuver that puts the ACL under stress [Marotta et al., 2019]. The increased risk of ACL injury of females athletes seems to be due to increased dynamic valgus and high abduction loads [Timothy E. Hewett et al., 2005]. Munro et al. showed the reliability and validity of the 2D frontal-plane projection angle (FPPA) to evaluate the dynamic valgus angle of the knee [Munro et al., 2012]. The aim is to assess the relationship between the dynamic valgus of the knee and the quadriceps muscular timing during a task that puts the ACL under stress.

Material & methods

Participants

After approval by the university's institutional review board and obtained the informed consent, we enlisted 60 athletes from youth classical ballet school (M = 10, 13.8 ± 1.2 y.; W = 10, 13.4 ± 1.8 y.), elite volleyball

teams ($M = 10, 26 \pm 3.9$ y.; $W = 10, 23.9 \pm 3.3$ y.), elite soccer team ($M = 10, 26.1 \pm 4.6$ y.; $W = 10, 23.9 \pm 3.3$ y.). Soccer and volleyball athletes underwent specific training for the sport (at least one day a week), and the dancers were involved in specific sports activities.

Drop fall

We used a 32cm platform to position the participant near the edge with the dominant leg off the step, with the athlete's weight supported by the non-testing limb. At an operator signal, the athlete had to move forward and drop vertically, without jumping or lowering his body, landing in a balanced position on the test limb, and holding on for five seconds. Before registering the test by sEMG, each athlete performed three tests to assure the correct movement. At the beginning of the evaluation, we recorded a quiet EMG period with no detectable muscle activity as the baseline. For each participant, we used the mean between two tests with the least variation.

sEMG

We collected the EMG data from four muscles: rectus femoris (RF), vastus medialis (VM), semitendinosus (ST), and biceps femoris (BF) of each subject's dominant leg. The skin over the bellies of these muscles was prepared for electrode placement by shaving and cleaning following SENIAM guidelines [Hermens et al., 1999]. We placed wireless surface electrodes (FREEEMG1000 - BTS bioengineering, Spa, Garbagnate Milanese MI, Italy) over the preparation sites of the muscle fibers. An inertial sensor (G sensor - BTS, Italy) determined when the testing foot first encountered the ground. An integrated software (EMG Analyzer - BTS) collected the EMG data at 1000 Hz to combine ground contact and muscular timing and define at what time the muscle activates before the forefoot touches the ground. Therefore, a shorter time will correspond to a late activation of the muscles in landing [Medina et al., 2008].

Dynamic Valgus Knee Angle.

A modified FPPA of the knee was measured as the angle subtended between the line from anterior superior iliac spine marker and the center of the intercondylar markers (not the patellar center) and the line from the center of the intercondylar markers to the ankle [Willson & Davis, 2008]. We assessed as DVK angle the difference between the static frame on the platform and the frame at the moment of contact of the forefoot with the ground (fig1), verified by two-dimensional (2D) video recordings and motion-analysis software (Kinovea - version 0.8.15, available for download at <http://www.kinovea.org>) [Bowerman et al., 2013; McLean et al., 2005; Munro et al., 2012; Schwartz et al., 2020].

Fig. 1

Statistical analysis

All statistical analysis was conducted using SPSS for Windows version 16.0 (SPSS Inc., Chicago, IL). We performed the Shapiro-Wilk test to assess data normality and independent t tests and ANOVA to evaluate differences between male and female athletes. All statistical tests were accepted as being statistically significant at $p < 0.05$. Correlations between thigh muscles timing activation (sec) and DVKa ($^{\circ}$) were examined using Pearson's correlation coefficient.

Results

All the results are shown as average $\pm$ SD (Table 1).

Table1

PRE-CONTACT MUSCLE ACTIVATION					DINAMIC VALGUS ANGLES						
		FA		MA				MA		FA	
VM B		219.2	±48.0	404.7	±52.7	DVKa		2,8	±1,4	5,8	±1,4
VM V		207.7	±52.4	402.4	±47.3	DVKa		3,1	±0,9	6,1	±0,9
VM S		204.7	±52.7	415.3	±51.4	DVKa		3,4	±1,3	6,4	±1,3
		FA		MA							
RF B		499.2	±90.6	601.7	±99.5						
RF V		489.2	±101.2	595.4	±107.3						
RF S		501.5	±97.4	577.1	±91.4						
		FA		MA							
BF B		204.2	±59.0	201.9	±56.1						
BF V		199.4	±55.4	204.1	±52.3						
BF S		210.1	±61.0	199.8	±64.1						
		FA		MA							
ST B		190.2	±52.3	190.2	±54.6						
ST V		200.1	±52.4	199.4	±55						
ST S		203	±51.1	194	±64.1						

VM= Vastus Medialis; B= Ballet; V=Volley, S= Soccer; DVKa= Dynamic Valgus Knee angle; MA= Male Athletes; FA= Female Athletes

The results demonstrated a significant late activation of the vastus medialis in female athletes, in all sport evaluated, compared to male athletes (MA=407 $\pm$ 6.1msec vs FA=210.5 $\pm$ 3.1msec). The same difference is reported between gender concerning the dynamic valgus angles of the knee (FA=6.1 $\pm$ 1.2degrees vs MA=3.1 $\pm$ 1.2degrees). The linear influence between the Vastus Medialis late activation (sec) and higher DVKa ($^{\circ}$) (Table 1). Statistically significant correlations ($p < 0.001$ for all sports groups) were found between the vastus medialis pre-contact timing and dynamic valgus knee angle. Pearson's r test ($t = 9.8403$, $df = 58$, $p\text{-value} < 0.05$) showed a significant correlation of 0.79. Multiple R-squared was 0.639 and we reported an Adjusted R-squared of 0.6245 ($p < 0.05$). (fig2).

Fig.2

Discussion

To determine the relationship between the dynamic knee valgus and the thigh musculature timing in female athletes, we correlated a 2D motion software dynamic angle analysis with sEMG data and inertial sensor during a task that puts the ACL under stress. A significant 79%, in correlation ($p < 0.05$), implies that there is a linear equation that describes the relationship between late timing of medial quadriceps fibers and an increase of the dynamic valgus knee in females compared to males (Fig.2). Athletes with increased dynamic valgus are at greater risk of injury to the anterior cruciate ligament, according to Hewett et al. [Timothy E. Hewett et al., 2005]. Muscular contractions can decrease the laxity in valgus of the knee threefold [Timothy E. Hewett et al., 2004]. But, dynamic malalignment does not seem to be exclusively a function of the extensor-flexor force balance [Schmitz et al., 2009]. Females demonstrated a decreased ratio of medial quadriceps to lateral quadriceps recruitment [Myer et al., 2005] and timing [Marotta et al., 2019]. Thus, Females with poor quadriceps medial compensation place the knee in a "dynamic valgus" position and hence at risk of ACL rupture when performing high-risk maneuvers [Myer et al., 2005]. Beyond age and the sport practiced, the results show that delayed activation of the medial quadriceps musculature [Marotta et al., 2019] in women is correlated with the dynamic angles of the valgus and thus an increased risk of ACL injury. Kinovea, despite the limitations of a video post-production software, proves to be a free, easy, reliable [Munro et al., 2012; Schwartz et al., 2020] tool. Despite the transverse and frontal motion planes that may influence the DVKa [McLean et al., 2005], a 2D video analysis is correlated with a drop jump task to assess the risk of ACL injury [Munro et al., 2017; Ugalde et al., 2015]. Despite this limitation, the small sample size, and it is the inability to underline a cause-effect relationship, different sports and ages could influence the study. But the sport heterogeneity demonstrates that the timing imbalance of the medial quadriceps is not linked to a specific competitive activity and does not change with the age of the athlete.

Conclusions

A simple, free, and available 2D motion software analysis combined with an sEMG and an inertial sensor may be able to assess the risk of ACL injury in female athletes. The late activation of the vastus medialis, hence a medial-lateral imbalance of the quadriceps, corresponds linearly to a larger dynamic angle in valgus. These findings can be useful for trainers because adequate neuromuscular training can induce a more protective motor strategy of the anterior cruciate ligament, influencing the medial-lateral ratio of quadriceps muscle activation.

Conflicts of interest

All authors declare that they have no sources of support in the form of sponsorships, grants, materials and that they have no interests, including grants, scholarships or commercial assistance or financial sponsorships received; or any relevant affiliation, organization or entity

References:

- Boden, B. P., Dean, C. S., Feagin, J. A., & Garrett, W. E. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopedics*. <https://doi.org/10.3928/0147-7447-20000601-15>
- Bowerman, E., Whatman, C., Harris, N., & Bradshaw, E. (2013). Reliability of 2D lower extremity alignment measures in elite adolescent ballet dancers. *New Zealand Journal of Sports Medicine*.
- Brophy, R., Silvers, H. J., Gonzales, T., & Mandelbaum, B. R. (2010). Gender influences: The role of leg dominance in ACL injury among soccer players. *British Journal of Sports Medicine*. <https://doi.org/10.1136/bjsm.2008.051243>
- Di Stefano, L. J., Martinez, J. C., Crowley, E., Matteau, E., Kerner, M. S., Boling, M. C., Nguyen, A. D., & Trojian, T. H. (2015). Maturation and sex differences in neuromuscular characteristics of youth athletes. *Journal of Strength and Conditioning Research*. <https://doi.org/10.1519/JSC.0000000000001052>
- Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., Disselhorst-Klug, C., & Hägg, G. (1999). European Recommendations for Surface ElectroMyoGraphy Results of the SENIAM project. *Roessingh Research and Development*.
- Hewett, T. E., Zazulak, B. T., Myer, G. D., & Ford, K. R. (2005). A review of electromyographic activation levels, timing differences, and increased anterior cruciate ligament injury incidence in female athletes. In *British Journal of Sports Medicine*. <https://doi.org/10.1136/bjsm.2005.018572>
- Hewett, Timothy E., Myer, G. D., & Ford, K. R. (2004). Decrease in neuromuscular control about the knee with maturation in female athletes. *Journal of Bone and Joint Surgery - Series A*. <https://doi.org/10.2106/00004623-200408000-00001>
- Hewett, Timothy E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G., Van Den Bogert, A. J., Paterno, M. V., & Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. *American Journal of Sports Medicine*. <https://doi.org/10.1177/0363546504269591>

- Ireland, M. L. (2002). The female ACL: Why is it more prone to injury? In *Orthopedic Clinics of North America*. [https://doi.org/10.1016/S0030-5898\(02\)00028-7](https://doi.org/10.1016/S0030-5898(02)00028-7)
- Leppänen, M., Pasanen, K., Kujala, U. M., Vasankari, T., Kannus, P., Äyrämö, S., Krosshaug, T., Bahr, R., Avela, J., Perttunen, J., & Parkkari, J. (2017). Stiff Landings Are Associated with Increased ACL Injury Risk in Young Female Basketball and Floorball Players. *American Journal of Sports Medicine*. <https://doi.org/10.1177/0363546516665810>
- Marotta, N., Demeco, A., de Scorpio, G., Indino, A., Iona, T., & Ammendolia, A. (2019). Late Activation of the Vastus Medialis in Determining the Risk of Anterior Cruciate Ligament Injury in Soccer Players. *Journal of Sport Rehabilitation*. <https://doi.org/10.1123/jsr.2019-0026>
- McLean, S. G., Walker, K., Ford, K. R., Myer, G. D., Hewett, T. E., & Van Den Bogert, A. J. (2005). Evaluation of a two dimensional analysis method as a screening and evaluation tool for anterior cruciate ligament injury. *British Journal of Sports Medicine*. <https://doi.org/10.1136/bjsm.2005.018598>
- Medina, J. M., Valovich McLeod, T. C., Howell, S. K., & Kingma, J. J. (2008). Timing of neuromuscular activation of the quadriceps and hamstrings prior to landing in high school male athletes, female athletes, and female non-athletes. *Journal of Electromyography and Kinesiology*. <https://doi.org/10.1016/j.jelekin.2006.11.009>
- Munro, A., Herrington, L., & Carolan, M. (2012). Reliability of 2-dimensional video assessment of frontal-plane dynamic knee valgus during common athletic screening tasks. *Journal of Sport Rehabilitation*. <https://doi.org/10.1123/jsr.21.1.7>
- Munro, A., Herrington, L., & Comfort, P. (2017). The relationship between 2-dimensional knee-valgus angles during single-leg squat, single-leg-land, and drop-jump screening tests. *Journal of Sport Rehabilitation*. <https://doi.org/10.1123/jsr.2015-0102>
- Myer, G. D., Ford, K. R., & Hewett, T. E. (2005). The effects of gender on quadriceps muscle activation strategies during a maneuver that mimics a high ACL injury risk position. *Journal of Electromyography and Kinesiology*. <https://doi.org/10.1016/j.jelekin.2004.08.006>
- Noyes, F. R., Barber-Westin, S. D., Fleckenstein, C., Walsh, C., & West, J. (2005). The drop-jump screening test: Difference in lower limb control by gender and effect of neuromuscular training in female athletes. *American Journal of Sports Medicine*. <https://doi.org/10.1177/0363546504266484>
- Rozzi, S. L., Lephart, S. M., Gear, W. S., & Fu, F. H. (1999). Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. *American Journal of Sports Medicine*. <https://doi.org/10.1177/03635465990270030801>
- Ryman Augustsson, S., & Ageberg, E. (2017). Weaker lower extremity muscle strength predicts traumatic knee injury in youth female but not male athletes. In *BMJ Open Sport and Exercise Medicine*. <https://doi.org/10.1136/bmjsem-2017-000222>
- Schmitz, R. J., Shultz, S. J., & Nguyen, A. D. (2009). Dynamic valgus alignment and functional strength in males and females during maturation. *Journal of Athletic Training*. <https://doi.org/10.4085/1062-6050-44.1.26>
- Schwartz, O., Talmy, T., Olsen, C. H., Dudkiewicz, I., Beese, M. E., Joy, E., Switzler, C. L., Hicks-Little, C. A., Mauntel, T. C., Padua, D. A., Stanley, L. E., Frank, B. S., DiStefano, L. J., Peck, K. Y., Cameron, K. L., Marshall, S. W., Wexler, R. S., Higinbotham, S., Blake, D., ... Hoch, J. M. (2020). How Reliable is Kinovea vs . TEMPLO in Knee and Hip Kinematics Assessment During Side Cutting Tasks? *Sports Health*. <https://doi.org/10.1016/j.clinbiomech.2020.01.010>
- Sutton, K. M., & Bullock, J. M. (2013). Anterior cruciate ligament rupture: Differences between males and females. In *Journal of the American Academy of Orthopaedic Surgeons*. <https://doi.org/10.5435/JAAOS-21-01-41>
- Ugalde, V., Brockman, C., Bailowitz, Z., & Pollard, C. D. (2015). Single Leg Squat Test and Its Relationship to Dynamic KneeValgus and Injury Risk Screening. *PM and R*. <https://doi.org/10.1016/j.pmrj.2014.08.361>
- Willson, J. D., & Davis, I. S. (2008). Utility of the frontal plane projection angle in females with patellofemoral pain. *Journal of Orthopaedic and Sports Physical Therapy*. <https://doi.org/10.2519/jospt.2008.2706>