Pattern Characterization of Running and Cutting Maneuvers in Relation to Non-contact ACL Injury

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During running and cutting maneuvers, the anterior cruciate ligament (ACL) is commonly injured by varsity athletes and recreational players alike. Previous work by Andriacchi and Camarillo named and kinetically defined two main types of cutting: Pattern 1 and Pattern 2. Pattern 1 is characterized by a positive spike in hip abduction moment followed by a maximum force straight through the knee. This is a stable landing as the subject changes direction, with the center of mass directly over the supporting limb. Pattern 2 is defined as any cut lacking the Pattern 1 characteristics. It is less mechanically stable, with the center of mass offset. Pattern determination through this method is based on analysis of motion capture and kinematic data gathered in the lab environment. The purpose of this study was to investigate whether a portable, video-based method could be used to categorize the subject's run and cut patterns instead of needing the lab environment and equipment. A video-based method would make it possible to test a large population of subjects in a short span of time and would allow testing outside the 'lab environment'—on the field or in the courts.

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Non-contact anterior cruciate ligament (ACL) injuries are common among both elite and recreational athletes. Research shows that such non-contact knee ligament injuries typically involve sudden changes in direction while the body is either accelerating or decelerating. This sort of motion, performed when a player sidesteps to change direction quickly, is referred to as a 'cut.' Thor Besier of the University of Western Australia recently completed two studies on the external loading of the knee joint during running and cutting maneuvers, which show that cutting while running puts the knee joint at higher risk of injury due to the heightened internal/external rotation forces perpendicular to...
cutting movement. These rotational forces perpendicular to the knee are known as 'moments.' Besier also suggests that loads experienced at the knee joint could also be related to the position of the foot with respect to the body's center of mass, as his study indicates the lean of the upper body leaned affected the stress of outward rotation at the knee.

Recent work by Professor Thomas Andriacchi’s Biomotion Research Lab at Stanford University supports Besier’s findings concerning the relation of the moment at the knee to the location of the body's center of mass.

In the work of both Andriacchi and Besier, a three-dimensional motion capture system and force plate were used to quantify forces and moments of subjects as a function of the location of their center of mass during run-and-cut maneuvers. This method of data collection, using the link model and the force plate, will be referred to as the kinetic method. The kinetic method allows cutting maneuvers to be biomechanically classified as one of two types: Pattern 1 and Pattern 2 (Fig 1). In a Pattern 1 cut, the center of mass remains along the tibial axis during the change in direction, while in Pattern 2 the center of mass is offset from the supporting limb. Pattern 2 cutting is expected to increase the possibility of knee buckling at landing.

Andriacchi’s study also compared the patterns of cutting by gender - 9 out of 10 male subjects exhibited Pattern 1 cutting, while 5 out of 9 female subjects demonstrated the more dangerous Pattern 2 cutting. This may indicate that women are more likely to cut in the less stable way. Interestingly, women are more than twice as likely to injure their ACL than men, and during military training, the odds of injury for women increase to 9.74 times the relative male injury risk. The high difference in ACL injury rate has been attributed to differences in male/female hip width, hormonal affects on ligament properties, increased joint laxity, and many other causes. Seventy percent of women's ACL tears are non-contact injuries, leading to the conclusion that perhaps the risk of ACL injury will decrease in women if they can be taught the Pattern 1 cutting style. Before acting toward this conclusion, however, the human factors that cause differences between the cutting patterns should be determined by examining the general population's overall incidence of Pattern 2 cutting. The kinetic method is, however, not an optimal method of data collection due to its time-consuming nature and equipment-intensive methodology. In order to determine a subject's cutting style more quickly, Jim Maltese has experimented with a visual method of categorizing cutting styles that examines direction and placement of the tibia in relation to the placement of the center of mass (Maltese, J., unpublished project report, 2001). Using conventional digital video technology, Maltese videotaped subjects performing cutting maneuvers and evaluated their motion frame-by-frame to categorize their pattern of cutting. If this video-based method is as accurate as the kinetic method, efficiency of testing subjects will increase greatly.

Purpose

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Methods and Materials

The kinetic and video-based methods were used simultaneously to evaluate the run-to-cut motion of the
subjects. The kinetic data collection method used a three-dimensional optoelectronic system for motion capture and a multi-component force plate to register the corresponding ground reaction force. Reflective markers were placed at 16 bony landmarks on each subject to allow full body tracking (Fig 2). Intersegmental forces and moments at the joints were then calculated using kinematics and kinetics as done in the Andriacchi - Camarillo project.6

After reflective markers were placed on the upper body and one leg of the subject, subjects followed verbal instructions from test personnel to begin from a black tapeline, 12 feet away from the plate, and run at a steady speed until they reached the force plate. With the foot planted squarely in the center of the plate, the subject was asked to perform a 90-degree side-step cut. This is a cut perpendicular to the direction of progression and away from the planted foot. This procedure was then repeated for the other leg.

For the video-based collection method, a digital video camera was set up such that the subject's frontal plane would be captured during the run-and-cut maneuver (Fig. 3). The camera was placed approximately 15 feet away from the subject at the point of cutting. After data collection, the tapes were viewed at normal and reduced speeds. In accordance with Jim Maltese's method, each lateral cut was first qualitatively categorized visually by watching the motion of the subject at normal speed (Fig. 4; unpublished project report, 2001). A second categorization was also made at a slow-motion playback, consisting of a quantifying displacement measurement was made using frame-by-frame pictures of the subject's deceleration (Fig 5). Both methods of categorizing based on video-based collection data are examined for their accuracy.

All data from the video-based method was analyzed before the kinetic analysis. This allowed for a blind comparison of pattern characterization based on video images alone before definite conclusions were drawn from the kinetic data.

The kinetic data was analyzed according to the process described by Andricachi and Camarillo. Analysis focused on the lower limb intersegmental forces and moments during the landing phase. All forces and moments were normalized by body weight and height. Forces were expressed as a percentage of body weight, and moments as a percentage of the product of body weight and height.

Andriacchi and Camarillo identified two patterns of limb loading during the landing phase of the run-to-cut maneuver. Pattern 1 was defined as having a hip abduction moment spike in the landing phase immediately followed by the absolute maximum component of the inter-segmental axial force vector at the knee (along the axis of the tibia; Fig. 6). Pattern 2 was defined by the absence of the two Pattern 1 characteristics, i.e., not having the combined hip abduction moment and peak knee force in the landing phase (Fig 6). The intersegmental forces at the knee and moments at the hip were evaluated for each trial of each subject. The subjects were then categorized according to the above Pattern 1 and Pattern 2 definitions.

To evaluate the video-based system, two female subjects (avg. age 21, height 73 inches, and weight 181) and five males subjects (avg. age 24, height 71.6 inches, and weight 179.1 lbs) volunteered for this study and were tested during walking, slow walking, fast walking, run, run to stop, and run-to-cut maneuvers following normal consent procedures. All subjects were free of musculoskeletal diseases or injuries that would influence function. Data collection took two hours per test in the Stanford Biomotion Laboratory.

Both described procedures, kinetic and video-based, were used simultaneously to categorize the cutting pattern of each subject. The results from the two methods were then compared.

**Results**

For the seven subjects, 36 total trials were collected for data comparison (both video and kinetic data were recorded for the same run-to-cut maneuver). Of the 36 trials, 14 were characterized correctly using the quantitative displacement measurement and 28 were characterized correctly with the qualitative visual method (Table 1). Statistical sensitivity, specificity, and odds ratios were also calculated for the visual characterization and displacement-measurement data.
sets (Table 2). The qualitative visual categorization method was shown to be most sensitive, most specific, and have the best odds.

The maximum displacement measurements for each trial were also analyzed against their corresponding kinetically determined patterns to see if there was any distinguishable trend. For example, though the negative displacement does not always indicate a Pattern 2 cut, there may be points where the cutting characterization could be made. Though between a peak displacement of (-0.10) and (+0.10) the data sets seem overlap, it is possible that any maximum displacement less than (-0.15) is always a Pattern 2. This possibility was investigated by graphing the maximum displacement measurement for each trial against the corresponding kinetic characterization (see Figure 3). As can be observed, however, there was no distinguishable correlation.

Discussion

Both video-based methods' results were not consistent with the results of the kinetic method. Comparison and statistical analysis show the qualitative visual categorization method to be more successful than the categorizations based on the quantitative displacement measurements. Categorization based on displacement vector was accurate only 39% of the time, while 78% of the time the visual categorization based on the digital video did match the kinetic method categorization.

Though none of the Sensitivity, Specificity, and Odds Ratio analysis was especially encouraging for either video-based method, the tests results may not be representative of our success, due to the small data set. However, even with this small data set, the Specificity rating and Odds Ratio for the visual method were considerably higher than for the displacement method. This, along with the comparative percentages of correct characterizations, indicates general promise for the video-based, visual categorization method as well as direction for further development.

An interesting observation was made in that many cutting trials declared Pattern 2 based on visual data but kinetically determined to be Pattern 1 were also noted to have the subject's arm raised in the opposite direction of the cut. This arm position could change the location of the subject's center of mass, so although the body is out to the side of the knee, the extended arm may keep the center of mass directly over the knee and foot in a more stable position (Fig. 7). Future research may develop this idea and may also reveal a link between freedom of motion of the arm in a sport and the incidence of ACL injuries, which are more common among basketball and volleyball players than among soccer players. In these sports players' arms are tied up in the game and not free to be used for balance or aligning their center of mass over the leg as they cut.

Collecting more data will clarify these issues as well as facilitate the development of a successful video-based, visual characterization method. Other factors affecting pattern type, including knee flexion, hip flexion, and upper-body posture, could be examined in order to find further identifiers for characterizing run-and-cut maneuvers. A second video camera could be added in order to record the subject's motion from a side view. Both lateral and frontal planes would then be observed during each trial, allowing the knee

![Fig. 3 Unitless Displacement of the knee versus time per cutting style](image-url)
flexion angle to be seen more clearly. Though the full body marker set was used to track the motion of the subject's torso, arms, and legs, the data collected on the upper body has not yet been analyzed. A larger link model needs to be developed first. The location of the center of mass could then be tracked more accurately throughout the run-and-cut maneuver. A dynamic model would allow the mass and motion of the subject's arms to be taken into account when estimating the location of the center of mass and would perhaps bring out additional, useful criteria for the video-based pattern categorization.

The results of this study indicate promise in developing a video-based, visual method for characterizing running and cutting patterns. In addition, observing videotapes of the testing allows additional details to be gathered concerning the subjects' motion during test runs. These observations point toward new avenues for development of a visual method - including arm position and lateral videotaping. The importance of arm placement for stability when cutting and the importance of consistent cutting patterns within individuals are additional directions for investigation. These topics could be investigated more easily once an accurate video-based method is completed. Large populations could then be tested using only one or two digital cameras. Data collection with the digital camera, video-based method is more efficient than the kinetic method, as digital cameras are relatively inexpensive and quite portable. A visual method of categorization would require relatively little testing time, as opposed to the hours necessary for the specialized motion capture and force plate system of the kinetic method. Using a video-based method, future research could quickly and easily determine trends across large populations and even conduct longitudinal studies in training and injury prevention, characterizing athletes at the beginning of the summer and checking on them throughout their training. For those who suffer non-contact ACL injuries, the results of this study and potential for future non-contact ACL injury biomechanics research are promising enough to warrant further work towards an accurate video-based approach to running and cutting pattern characterization.

References and Notes

1. Three of the male subjects were players on Stanford's Varsity Men's Soccer Team, one was the Varsity Men's Soccer Assistant Coach, and the final male subject was an average 28 year old. The two female subjects were players on Stanford's Varsity Women's Basketball Team.


Acknowledgements

The author gratefully acknowledges Dr. Thomas Andriacchi of the Stanford Biomotion Lab Research Group for the opportunity to work under his direction, Chris Dyrby of the Stanford Biomotion Lab Research Group for his invaluable assistance with the project. Others critical to the success of this project were Dr. Gene Alexander, Ajit Chaudri, and Rich Bragg of the Stanford Biomotion Lab. David Camarillo and Jim Maltese are thanked as well for their hard work on this project's foundational studies.