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*Research Paper*

# Landing technique affects knee loading and position during the stop phase of run-to-stop maneuvers

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**ABSTRACT**

Many non-contact Anterior Cruciate Ligament (ACL) injuries in female basketball athletes occur during Run-To-Stop (RTS) maneuvers. However, no study has quantified the effect of landing technique on lower extremity biomechanics in RTS tasks frequently utilized during basketball events. The objective of this study was to evaluate the effects that the landing techniques have on lower extremity biomechanics during stop phase of RTS maneuvers. Twenty (20) healthy female collegiate basketball athletes used either a forefoot or rearfoot landing technique to perform RTS maneuvers. Biomechanical variables of the non-dominant leg were measured and analyzed during the stop phases of RTS maneuvers. Subjects presented increased peak knee flexion angle (P =0.047) and peak knee extension moment (P =0.029) during the stop phase of RTS maneuvers using rearfoot landing technique as compared to forefoot landing technique. The rearfoot landing technique increased knee extension moment, which can potentially place a higher strain on the ACL. Forefoot landing technique may be targeted in ACL injury prevention programs.

**Key words:** Anterior cruciate ligament injury, basketball, biomechanics, run to stop, landing technique.

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## INTRODUCTION

Videotapes of ACL disruptions show that most non-contact injuries occur with the knee close to extension during a sharp deceleration or landing maneuver (Boden et al., 2000). Higher ground reaction forces when landing in an extended knee position suggests lower flexion angle is a contributing factor in non-contact ACL injury (Podraza and White, 2010). In addition, female subjects prepared for landing with decreased hip and knee flexion at landing may result in increased ACL loading during the landing of the stop-jump task and the risk for non-contact ACL injury (Chappell et al., 2007).

It was indicated in a study that it is highly probable that ACL injuries are more likely to occur during multi-planar rather than single-planar mechanisms of injury (Quatman et al., 2010). Anterior drawer load in isolation was insufficient to rupture the ACL without additional valgus load (McLean et al., 2004). In addition, knee joint valgus is often implicated as a hazardous position for the ACL (McLean et al., 2004; Ford et al., 2003) and has been linked to ACL injury risk (Hewett et al., 2005).

Boden et al. (2009) analyzed videos of non-contact ACL injuries during basketball games. They reported that ACL injuries commonly occurred with heel contact strategy at initial ground contact. Additionally, foot placement at landing has been linked to lower limb loading and injury in running (Kulmala et al., 2013; Lieberman, 2012; Williams et al., 2000; Almeida et al., 2015) pivot and side step cutting maneuvers (Cortes et al., 2012) but has not been thoroughly investigated in rapid deceleration movements such as the run-to-stop (RTS). Landing technique may have important effects on lower extremity biomechanics during the stop phase, which has greater risk in run-to stop maneuvers. However, to our knowledge, no study has quantified the effect of landing technique on lower extremity biomechanics during stop phase of RTS tasks frequently utilized during basketball events.

Therefore, the objective of this study was to evaluate the effect the landing technique has on lower extremity

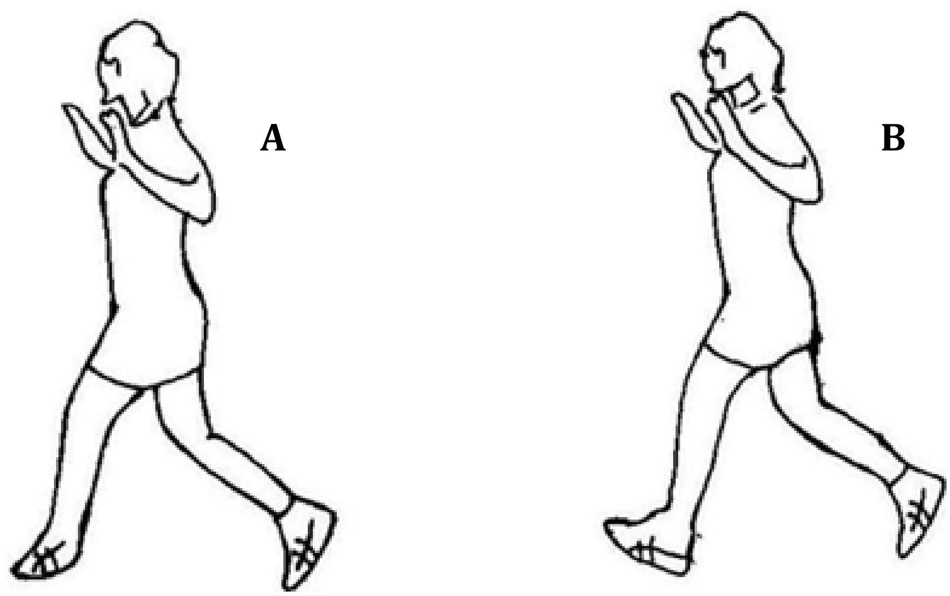


**Figure 1:** Participants perform run-to-stop maneuver. A) forefoot landing; B) Rearfoot landing.

biomechanics during the stop phase of RTS maneuvers. We hypothesized that rearfoot landing technique would produce significant increased knee valgus angle and knee moment, but decreased knee flexion angle during the stop phase of RTS maneuvers.

## MATERIALS AND METHODS

### Participants

Twenty (20) healthy female collegiate basketball athletes provided written consent to participate in this study. The power for each analysis of variance was not less than 0.05 if the effect size was more than 0.80 (Cohen, 1998). A *priori* power analysis by G*Power revealed that obtaining a static power of 0.75 at an effect size of 0.80 with an alpha level of 0.05 required a sample size of at least 19 subjects. The participants' average age, height, mass and history of playing basketball were 22.6 ± 1.5 y, 169.7 ± 5.9 cm, 61.2 ± 7.3 kg, and 8.1 ± 2.4 y, respectively. Participants were screened to ensure that nobody had any previous ACL injury/surgery, including no injuries on hip, low back, knee or severe ankle within the last six months or surgeries within the last 2 years. The dominant leg was defined as the leg usually used for kicking a soccer ball (Greenberger and Paterno, 1995). Approval for this study was obtained from the review board of Taishan Medical University (ID number, 201401).

### Procedures

General anthropometric measures (height and weight) were taken for each participant by the same researcher. Participants completed a 5-min running warm-up wearing basketball shoes before data collection. After the warm-up, reflective markers were placed on specific body landmarkers (anterior superior iliac spine, posterior superior iliac spine, thigh, knee, tibial, ankle, toe and heel) according to the Plug-In Gait marker set (Tamura et al., 2017). Participants were required to perform the following two conditions (forefoot landing and rearfoot landing) randomly during the stop phase of RTS tasks (Figure 1). Participants ran forward 5 m and land their non-dominant leg on a force platform (9287B, Kistler Corporation, Switzerland) embedded in the floor, immediately stopping in a low ready position (eyes forward, legs wide and slightly bent). All participants indicated the right leg as their dominant leg. The non-dominant leg was adopted as the plant leg because the majority of surgical limbs in ACL reconstruction are non-dominant leg (Bjorjnaraa and Di, 2011). Participants were given three practice trials for each technique. A RTS trial was deemed successful if the participant performed the maneuver at a speed of 4 to 5 $ms^{-1}$. Every participant performed three successful trials verified by video per condition.

### Data collection

A 16-camera motion analysis system (Vicon MX series, camera MXT20-s, Oxford Metrics, UK) was used to obtain frontal and sagittal plane kinematic parameters of the non-dominant lower extremity at a sampling rate of 200 Hz. Four 90 × 60 cm force plates (9287B, Kistler Corporation, Switzerland) were employed to capture ground reaction force data at a sampling rate of 1200 Hz. The ground

**Table 1:** The comparison of knee flexion angle, valgus angle, extension moment and valgus moment between run-to-stop maneuvers using forefoot landing and rear foot landing technique.

| Variable | Forefoot landing | Rear foot landing | Confidence interval | *p value* | Effect size |
|---|---|---|---|---|---|
| Peak knee flexion angle (°) | 25.9 ± 6.9 | 26.2 ± 6.9 | -2.09 ~ 2.76 | 0.761 | 0.10 |
| Peak knee valgus angle (°) | 46.4 ± 22.6 | 49.1 ± 24.2 | 0.21 ~ 5.78 | 0.036* | 0.63 |
| Knee flexion angle at IC (°) | 8.5 ± 4.2 | 8.9 ± 5.6 | -2.48 ~ 1.70 | 0.683 | 0.14 |
| Peak knee extension moment (Nm $kg^{-1}$ $m^{-1}$) | 2.9 ± 0.8 | 3.2 ± 0.7 | -0.56 ~ -0.04 | 0.029* | 0.66 |
| Peak knee valgus moment | -0.9 ± 0.7 | -0.8 ± 0.4 | -0.46 ~ 0.29 | 0.615 | 0.17 |

*Significant difference between run-to-stop maneuvers using forefoot and rear foot landing technique ($p < 0.05$).

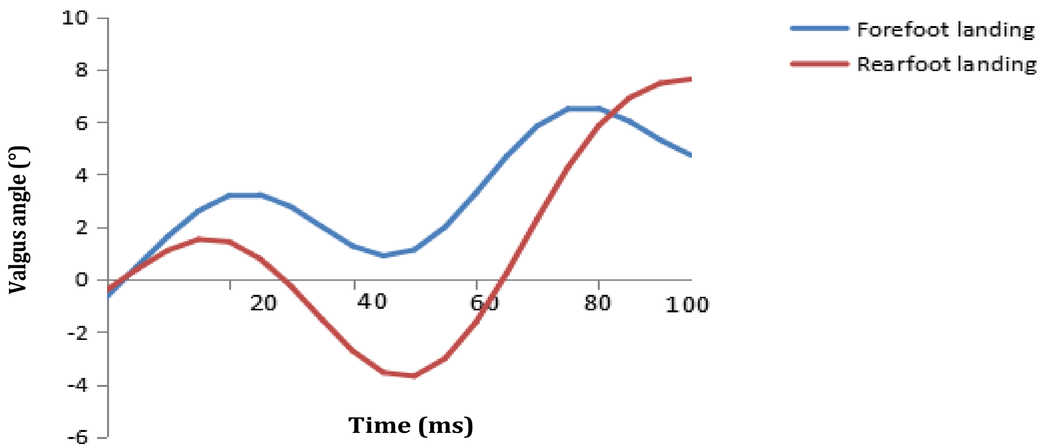


**Figure 2:** Temporary change of the knee valgus/varus angles during the stop phase of run-to-stop maneuver. Data represent average of all trials of each landing technique for one participant. Negative values indicate varus angle.

reaction force and kinematic data were sampled simultaneously using the Vicon system. A standing trial with the participants standing on the force plates with arms abducted at 90° was obtained. From the standing trial a kinematic model (pelvis, thigh, shank and foot) was created for each participant. During each RTS maneuver, ground reaction force data and marker trajectories were low-pass filtered with a quintic spline (Woltring et al., 1985) at a cut-off frequency of 12 Hz (Ramsay et al., 2016). A standard inverse dynamics analysis using segment inertial characteristics estimated for each participant as per the methods of Dempster (Dempster, 1955) was employed to capture the kinematic and ground force data to calculated 3D joint moments. The stop phase was defined from initial contact (IC) as the moment when vertical ground reaction force was higher than 10 N (Tamura et al., 2017), until the maximum knee flexion. Joint moments were normalized to mass and height (Nm $kg^{-1}$ $m^{-1}$).

## Statistical analysis

Average values from five trials were used for analysis. The statistical analyses were performed using the Statistical Package for the Social Sciences version 19.0 J for Windows. Knee flexion angle at IC, peak knee flexion angle, peak knee valgus angle, peak knee extension moment and peak valgus moment between RTS maneuvers using forefoot and rearfoot landing techniques were compared using a paired samples t-test. The level of probability accepted as the criterion for statistical significance was $p < 0 .05$.

## RESULTS

The mean ankle plantar flexion angle at IC was 20.8±5.4° during the RTS maneuvers using forefoot landing technique, while the mean dorsiflexion angle at IC was 6.7±7.9° during the RTS maneuvers using rearfoot landing technique. There was a significant difference for peak knee flexion angle between RTS maneuvers using forefoot and rearfoot landing techniques ($p < 0.05$) (Table1). However, the difference between the knee flexion angle at IC of RTS maneuvers using forefoot and rearfoot landing techniques was not significant (Table 1) ($p>0.05$).

The temporary changes of the knee valgus/varus angles during the stop phase of RTS maneuver formed a bimodal curve (Figure 2). However, the difference between the peak

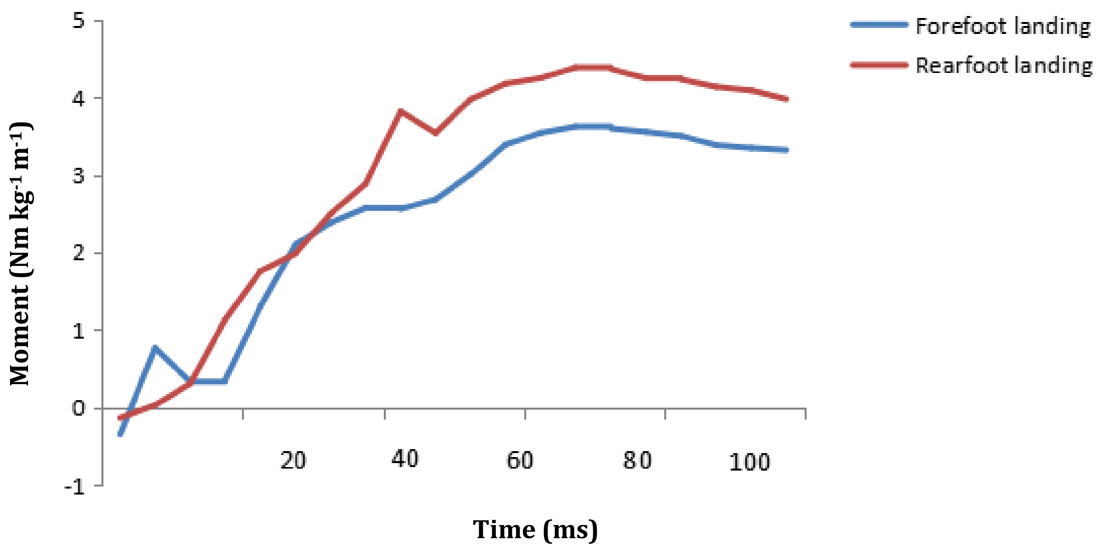


**Figure 3:** Temporary change of the knee extension/flexion moments during the stop phase of run-to-stop maneuver. Data represent average of all trials of each landing technique for one participant. Negative values indicate flexion moment.

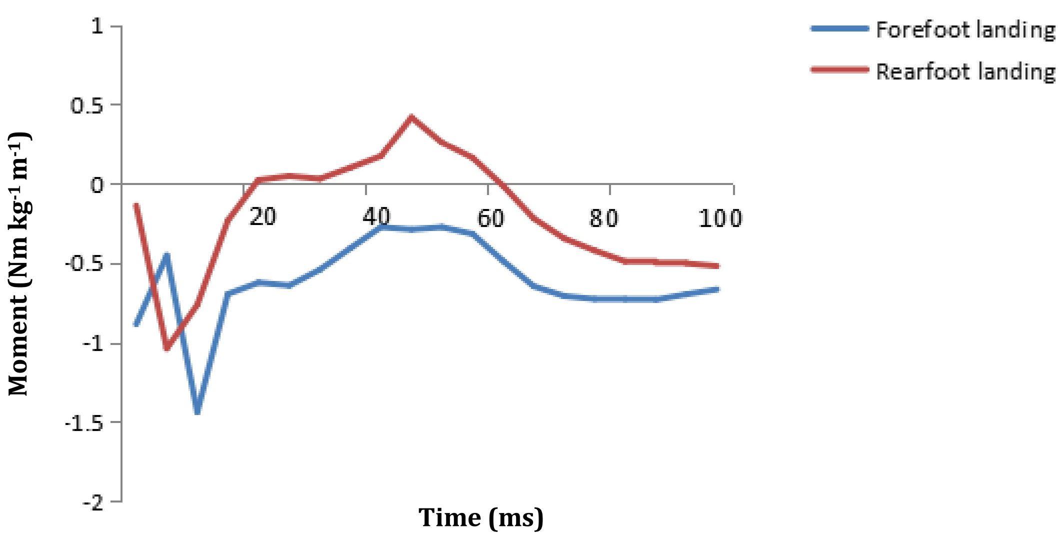


**Figure 4:** Temporary change of the knee varus/valgus moments during the stop phase of run-to-stop maneuver. Data represent average of all trials of each landing technique for one participant. Negative values indicate valgus moment.

valgus angles during the stop phase of RTS maneuvers using forefoot and rearfoot landing techniques was not significant (Table 1) ($p > 0.05$).

Figure 3 shows the temporary change of the knee extension/flexion moment during the stop phase of RTS maneuver. The peak knee joint extension moment during the stop phase of RTS maneuvers using forefoot and rearfoot landing techniques were 2.90 ± 0.80 Nm $kg^{-1}$ $m^{-1}$ and 3.20 ± 0.70 Nm $kg^{-1}$ $m^{-1}$, respectively and the peak knee extension moment during the stop phase of RTS maneuvers using forefoot landing technique was significantly lower than that during the stop phase of RTS maneuvers using rearfoot landing technique ($p < 0.05$) (Table1).

Figure 4 shows the temporary change of the knee varus/valgus moment during the stop phase of RTS maneuver. The peak knee joint valgus moment during the stop phase of RTS maneuvers using forefoot and rearfoot landing techniques were 0.39 ± 0.36 Nm $kg^{-1}$ $m^{-1}$ and 0.84 ± 0.16 Nm $kg^{-1}$ $m^{-1}$, respectively and the difference between the peak valgus moment during the stop phase of RTS maneuvers using forefoot and rearfoot landing techniques was not significant ($p > 0.05$) (Table1).

## DISCUSSION

The present study evaluated the impact of forefoot and rearfoot landing on lower limb biomechanics during the stop phase of RTS maneuvers. In line with our initial hypothesis, rearfoot landing presented an increased knee extension moment during the stop phase of RTS maneuvers as compared with forefoot landing. Participants using rearfoot landing also presented significant increased peak knee flexion angle compared to forefoot landing during the stop phase of RTS maneuvers. The knee joint extensor moment increased when the knee axis moved forward relative to the resultant reaction force vector (Podraza and White, 2010). Therefore, rearfoot landing presented an increased knee extension moment during the stop phase of RTS maneuvers when compared with forefoot landing. Developing individualized intervention strategies that focus on minimizing knee loading combined with proper landing technique have been proposed (Hewett et al., 2005; Renstrom et al., 2008).

The results of the current study demonstrated that during the stop phase of RTS maneuvers, participants did not present significant increased knee valgus angle and decreased knee flexion angle at IC as compared to forefoot landing. These results was somewhat surprising given that previous research reported that participants had increased knee valgus angle and decreased knee flexion angle at IC with rearfoot landing (Kovacs et al., 1999). In addition, Cortes et al. (2012) reported that participants presented increased peak knee flexion angle and decreased knee flexion angle at IC when performing the rearfoot landing technique in comparison to the other techniques. One possible reason for the difference between the studies is the different methodological practices. Cortes et al. (2012) utilized sidestep cutting and pivot with rapid deceleration following change of direction. In the current study, participants had to perform forefoot landing and rearfoot landing randomly and stop immediately. The difference in the respective task demands may explain the lack of change in knee valgus angle and flexion angle.

The difference between the peak valgus moment during the stop phase of RTS maneuvers using forefoot landing and rearfoot landing techniques was not significant. The forefoot landing technique had significantly higher internal knee adductor moment than the rearfoot landing technique for both the pivot and sidestep cutting task (Cortes et al., 2012). Several studies and concepts of motor control support the notion that the multiple risk factors can vary with different task constraints (Cortes et al., 2011; Newell, 1996).

Certain limitations of this study should be addressed. First, the present study is an experimental study and does not completely simulate the actual RTS maneuver in real-life basketball competitions. Analysis of the aspects influencing RTS such as speed and striking wide is necessary. Finally, the present study only analyzed the non-dominant leg. A previous study reported that peak knee valgus angle of the dominant leg in female athletes is significantly greater than that of the non-dominant leg during landing (Ford et al., 2003). We plan to examine the differences of the knee flexion angle, knee valgus angle and knee moment of the non-dominant as well as, the dominant leg during RTS maneuvers in future studies.

In summary, the observed biomechanical differences between RTS maneuvers using different landing techniques suggest that the landing technique presents different characteristics and the injury mechanism may depend on the combination of landing technique and the specific movement. Rearfoot landing technique places female basketball athletes in a more extension moment, which can potentially place a higher strain on the ACL, especially hip and trunk which cannot decrease knee load effectively.


## ACKNOWLEDGMENT

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