한국운동역학회지, 2009, 제19권 2호, pp. 369-377
Korean Journal of Sport Biomechanics
2009, Vol. 19, No. 2, pp. 369-377

축구화 스터드 형태에 따른 무릎 모멘트의 변화

Changes in Knee Joint Loading on Infilled Turf with Different Soccer Cleat Designs

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ABSTRACT

S. K. PARK, J. S. LEE, S. B. PARK, and D. Stefanyshyn, Changes in Knee Joint Loading on Infilled Turf with Different Soccer Cleat Designs. Korean Journal of Sport Biomechanics, Vol 19, No 2, pp. 369-377, 2009. The purpose of this study was to determine the relationship between different soccer cleat designs and knee joint moments. Twelve physically active males (mean(SD): age: 26.4(6.2)yrs; height: 176.4(4.1)cm; mass: 74.0 (7.4)kg) were recruited. Kinematic and force plate data were collected for all subjects during normal running and a 45° cutting maneuver, called a v-cut. Both motions were performed at 4.0±0.2 m/s on infilled artificial turf with three pairs of soccer cleats of different sole plate designs, and one pair of neutral running shoes. Inverse dynamics were used to calculate three dimensional knee joint moments, with repeated measures ANOVA and post hoc paired Student's t-test used to determine significance between shoe conditions. Significant differences were found in the extension moments of the knee for running trials, and for external rotation and adduction moments in the v-cutting trials. Knee moments were greater in v-cut than running, and the traditional soccer cleats (Copa Mondial and World Cup) tended to result in greater knee moments than the Nova runner or TRX soccer cleat. Cleat design was found to influence 3-dimensional knee moments in a v-cut maneuver. In the translational traction test, there were significant differences between all conditions. In the rotational traction test, friction with soccer shoes were greater than friction with running shoes. However, no differences were found between soccer shoes. Higher moments may lead to increased loads and stresses on knee joint structures, and thus, greater injury rates.

KEYWORDS : KNEE MOMENTS, TRACTION, ROTATIONAL TRACTION, RUNNING, CUTTING MOVEMENT

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Ⅰ. Introduction

During sports activities, injuries occurring at the knee joint are generally classified as either contact or non-contact in nature. Whereas contact injuries result from a direct blow to the knee and are difficult to prevent, particularly in sports such as football and soccer, non-contact injuries are usually due to foot fixation, hyperextension and torsional stresses (Baker, 1990), with some success seen in preventing these types of injuries with proper movement pattern training (Arendt & Dick, 1995; Baker, 1990). Epidemiological data suggested the latter type of injury mechanism to be the most common, accounting for up to 75 percent of injuries to the knee and associated soft tissue structures (Arendt & Dick, 1995; Baker, 1990; McLean, Neal, Myers & Walters, 1999).

It has been reported that a valgus stress on the knee can produce tension in the medial supporting structures, while varus motions stress the lateral aspect of the knee (Baker, 1990). When excessive and coupled with rotation, these forces can lead to injury or ligament rupture (Baker, 1990; Malinzak, Colby, Kirkendall, Yu & Garrett, 2001; McLean, Neal, Myers & Walters, 1999). Cutting maneuvers, which involve planting to change direction, are common to many team sports and are motions that produce high valgus or varus stresses, depending on the direction of the cut. If high rotational friction between the shoe and surface exists, foot fixation on the field of play may result during the cutting maneuver (Baker, 1990). This situation then influences the loading and moments occurring at the knee (Stefanyshyn, 2003).

Many studies have examined the relationship between the shoe-surface interface (Andreasson, Lindenberger, Renstrom & Peterson, 1986; Bonstingl, Morehouse & Niebel, 1975; Cawley, Heidt, Scranton, Losse & Howard, 2003; Heidt, Dormer, Cawley, Scranton, Losse & Howard, 1996; Lambson, Barnhill & Higgins, 1996; Majid & Bader, 1993; Torg, Quedenfeld & Landau, 1974 ; Torg, Stilwell & Roger, 1996; Valiant, McGuirk, McMahon & Frederick, 1985; van Gheluwe, Deporte & Hebbelinck, 1983), usually with mechanical testing apparatuses, in order to quantify the friction produced. The general assumption is made that higher friction in a particular shoe-surface combination leads to increased injuries, yet few studies have looked at the resultant forces produced at the knee.

Scott and Winter(1990) used a standard 2-D inverse dynamics approach to calculate the resultant internal knee joint moments during running. Their analysis provided a good estimation of joint loading at several common injury sites (Stefanyshyn, 2003), showing a peak knee extension moment of 145Nm (Scott and Winter, 1990). As their calculations were only in two dimensions, the knee moments acting in the transverse and frontal planes were unavailable. Yet it is precisely these moments that are crucial to knee injury, as they lead to torsion and bending stresses on the joint (Stefanyshyn, 2003). Scott and Winter's results, however, were supported by Besier and colleagues(2001), who performed a similar analysis to determine 3-D loading patterns during barefoot running and cutting maneuvers. The knee was subjected to a peak flexion load of 150Nm, a peak valgus(abduction) load of 40Nm and a peak internal rotation of 24Nm during a sidestepping maneuver at a speed of 3m/s (Besier et al., 2001), all of which were significantly higher than the loads experienced in running. It should be noted that these values were for the external loads placed on the knee during the tasks specified.

Other studies have focused on the kinematics involved in various cutting maneuvers, and possible differences across genders (Malinzak, et al., 2001; McLean, et al., 1999), or on the frictional characteristics of the shoe-surface interface (Andreasson, et al., 1986; Bonstingl, et al., 1975; Cawley et al., 2003; Heidt et al., 1996; Lambson, et al., 1996; Majid & Bader, 1993; Torg, et al., 1974 ; Torg, et al., 1996; Valiant et al., 1985; van Gheluwe, et al., 1983). Little has been done, however, in examining how cleat design, or the relationship between the shoe and surface influence the loading of the knee. Torsional resistance has been linked to increased injuries (Arendt & Dick, 1995; Lambson, et al., 1996; Torg, et al., 1974), yet the mechanism of how traction affects knee joint injury remains unknown. We hypothesized that cleat design will influence joint moments at the knee during a cutting maneuver, but have little effect during normal running motion. Therefore, the purpose of this study was to determine the relationship between soccer cleat designs and knee joint moments.

Ⅱ. Methods

Twelve physically active male volunteers with size 9 (US) feet and no previous major injuries to the lower extremity were recruited for this study. The average age of subjects (mean(SD)) was 26.4(6.2)years, while average height and mass were 176.4(4.1)cm and 74.0(7.4)kg, respectively. All subjects completed an informed written consent form in accordance with the University of Calgary Ethics Committee.

Three retro-reflective markers were placed on each of the shoe, shank and thigh of the right leg of the subjects. Additional markers were placed on the medial and lateral femoral epicondyles and the medial and lateral malleoli of the ankle in order to determine joint centers in a neutral trial for each shoe condition, following which those markers were removed.

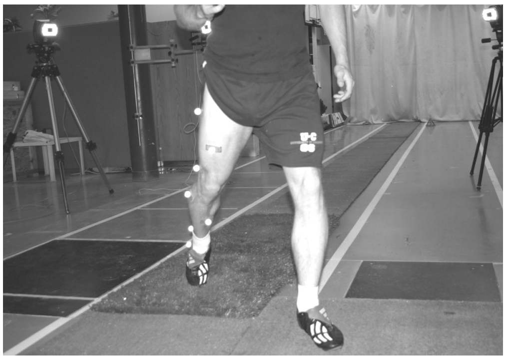

Figure 1. Cutting movement on infilled turf

Figure 2. Shoes used in this study. A) Adidas Supernova running shoe ("Nova"); B) Adidas Copa Mondial soccer cleat ("Copa"); C) Adidas World Cup soccer cleat ("World"); D) Adidas X-TRX Soft Ground soccer cleat ("Trx").

Subjects were then asked to perform two movements: normal straight running, with the stance phase of the right leg occurring while contacting a force plate, and a v-cut maneuver, describes as running straight followed by a 45° cut to the left (inside) when the right foot contacts the force plate(Figure 1).

Each movement was performed at 4.0±0.2m/s, as measured by timing lights placed before and after the force plate, 1.8 meters apart at chest height. In order to collect accurate data sets at the selected running speed, the actual distance(0.9m+0.9m/cos45°) due to a 45° cut was considered. Trials were only selected if they were within 5% of the defined running speed. These movements were done in four shoes (see Figure 2)

1) the Adidas Supernova neutral running shoe;
2) the "Copa Mundial" traditional soccer boot by Adidas, having 12 molded studs: 4 on the heel with 12mm tip diameter and 12mm length, 8 studs on the anterior portion of the boot with 10mm tip diameter and 10mm length;
3) the "World Cup M" six-stud soccer boot by Adidas, with 6 aluminum-tipped screw-in studs: 2 on the heel of 9mm tip diameter and 15mm length; and 4 on the forefoot with 9mm tip diameter and 12mm length; and
4) the "X-TRX Soft Ground" multi-type soccer boot by adidas, with 9 oblong, bar-shaped molded studs: 2 on the heel measuring 16mm high by 14mm long by 5mm wide, and 7 on the forefoot with dimensions of 13mm high, 11mm long and 5mm wide.

Eight trials were performed per condition, for a total of 16 trials per shoe, or 64 trials per subject. Matlab program(Mathworks, USA) was used to randomly assign the order of shoes and movement conditions to be performed.

Kinematic data were collected with eight high-speed Eagle digital motion capture cameras (240Hz, Motion Analysis Corp., Santa Rosa, CA), while ground reaction forces were collected with a 600 x 900mm force plate (2400Hz, Kistler, Winterthur, Switzerland). <Figure 3> shows that the force plate was covered with a 600 x 900 x 50mm piece of infilled artificial turf (FieldTurf, USA) in the middle of capture volume.

Inverse dynamics, and more specifically, the knee joint moments in the transverse, frontal and sagittal planes were calculated with KinTrak software (v. 6.0, University of Calgary, Canada).

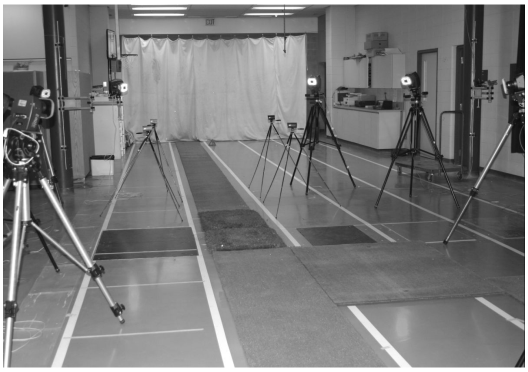
Figure 3. Experimental setup for motion test

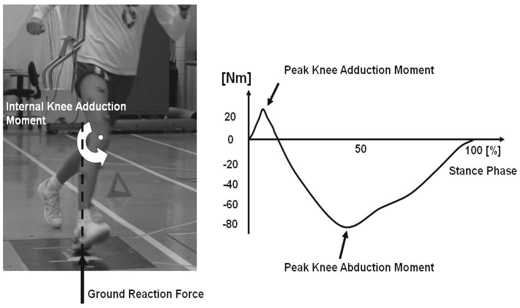

Figure 4. Calculation of internal knee adduction and abduction moment in the frontal plane during cutting movement (modified with permission from Park et al., 2009)

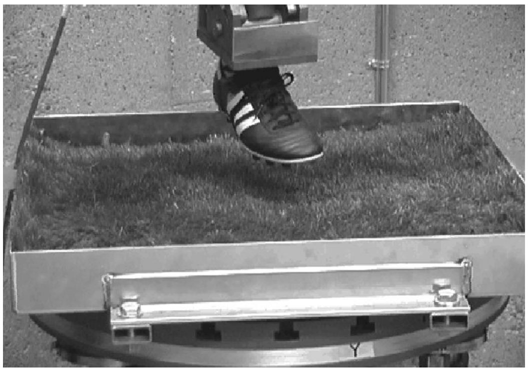
Figure 5. Mechanical testing for traction

Peak internal knee joint moment indicted the three dimensional torque or twisted loading at the knee. <Figure 4> shows how peak internal knee adduction and abduction moments is created about knee joint center from the frontal view during cutting manoeuvre(Park, Stefanyshyn, Ramage, Hart &

Ronsky, 2009).

Automated Footwear Testing System(AFTS) was used for a friction test (Figure 5). The system allows realistic loading conditions and relative movements of the shoe on the surface. The system consists of a Stewart Platform that moves the ground with six degrees of freedom relative to a fixed foot and shoe. A six axis load cell is connected to the foot to measure the relative force and moments. For Translational traction test, the shoe was dorsi-flexed 10 degrees and lowered onto the surface until a vertical ground reaction force of 400N was reached. The surface was then moved anteriorly to the shoe by 30cm. Translational friction coefficients were calculated by dividing the horizontal resistance force by the vertical load.

For rotational traction test, again the shoe was dorsi-flexed 10 degrees with respect to the turf surface, and initially loaded with 400N of vertical force. The platform was rotated 30 degrees counterclockwise about a point in the center of the shoe contact area. Rotational friction coefficients were calculated from the free moment of rotation.

A Statistical software package (SPSS v. 12.0, Chicago, IL) was used to ascertain differences between shoes: a repeated measures ANOVA was used to compare conditions, and post hoc analysis was performed with a paired Student's t-test. The significance level was set at $\alpha<.05$.

Ⅲ. Results

The peak moments acting on the knee in the transverse, frontal and sagital planes as well as the peak vertical ground reaction force for both the running and v-cut trials are shown in (Table 1).

Running; No significant differences were found between shoe conditions in the running trials for the peak vertical ground reaction force (1872-1900N), or the peak moments in the frontal plane of the knee (ab-/adduction moment), which ranged from 56.9 to 60.7Nm of abduction. There was no difference in peak external rotation moments (6.7-9.1Nm). In the sagittal plane, the peak knee extension moment of both the Copa (168.8Nm) and Trx (171.5Nm) soccer cleats were significantly lower than the extension moment when wearing the Nova runner (186.5Nm). P values for this difference were: p=.01 and .00, respectively.

V-cut; There were no statistically significant differences in the vertical ground reaction forces (1872-1891N) produced between shoe conditions when subjects performed a v-cut. In the transverse plane, both the Copa (55.3Nm) and World (51.8Nm) cleats had external rotation moments significantly higher from the Nova runner (46.9Nm), p=.00 and .01, respectively. For the frontal plane knee moments, a statistical difference was found in peak adduction moments between the Nova runner and Copa cleats (p=.00), and the Nova runner and World cleats (p=.00), both of which were greater that the Nova runner. In addition, the adduction moment with the World cleats was significantly higher than that of the Trx cleats (86.2 vs. 77.3Nm, respectively, p=.02). No differences were found in the sagittal plane moments acting on the knee joint during the v-cut maneuver.

Mechanical Traction; <Figure 6> shows static traction coefficients from the traction test.

In the translational traction test, there were significant differences between all conditions. In the rotational traction test, friction with soccer shoes were greater than friction with running shoes (Figure 7). However, no differences were found between soccer shoes.

Table 1. Peak knee joint knee moments (Nm) and vertical ground reaction force (N), GRF, during running and a v-cut maneuver in four cleat designs. Data are (mean (SD)).

	Plane	Variable	Cleat Design			
			Nova	Copa	World	TRX
RUN	Transverse	External Rotation	9.1(7.4)	6.7(6.7)	8.5(9.4)	9.0(9.3)
	Frontal	Abduction	58.8(21.9)	60.7(23.4)	56.9(24.8)	57.2(22.1)
	Sagittal	Extension	186.5(50.2)	168.8(48.5)*	176.0(45.4)	171.5(52.2)*
		GRF	1888(235)	1900(245)	1872(242)	1882(231)
VCUT	Transverse	External Rotation	46.9(19.9)	55.3(21.9)*	51.8(20.0)*	50.7(25.9)
	Frontal	Abduction	72.5(39.0)	87.2(40.0)*	86.2(37.7)*	77.3(37.4)**
	Sagittal	Extension	198.6(33.0)	193.4(42.7)	194.3(38.9)	186.2(40.9)
		GRF	1872(302)	1881(361)	1891(311)	1884(367)

*significantly different from Nova, $p<.05$; ** significantly different from World $p<.05$

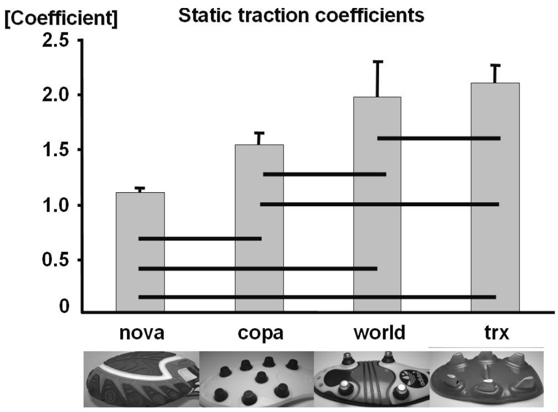

Figure 6. Static traction coefficients during translational traction test

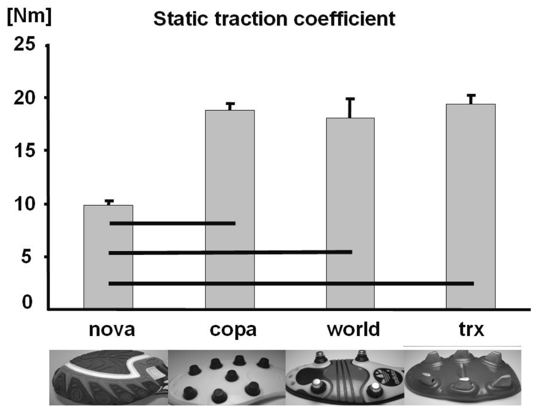

Figure 7. Static traction coefficients during rotational traction test

Ⅳ. Discussion

The purpose of this study was to determine the relationship between soccer cleat designs and knee joint moments. Of the four shoes and two motions tested, several differences were found. Our hypothesis was that no differences would exist in the running condition. This was indeed the case for all variables, save the peak extension moment where the Nova runner was higher than the Copa or Trx cleats. The internal extension moment of the knee is created by both muscle and soft tissue forces (Stefanyshyn, 2003) in order to counteract the flexion moment imposed by the ground reaction force. As there were no differences in the peak vertical ground reaction force between shoe conditions, the reasons for the observed difference in extension moments would be due to the combination (direction and magnitude) of all three components(vertical, medial/lateral and anterior/posterior forces) of ground reaction force and relative position of knee joint center during stance phase.

Our hypothes is also predicted differences in knee moments during the v-cut maneuver. These were found in the transverse and frontal planes, where, in both cases, the moments created while wearing the Copa and World cleats were significantly higher than with the Nova runner. This seems to suggest similar fictional characteristics and force distribution properties between the Copa and World cleats, while the Trx cleat more closely resembles the running shoe. However, from the results of the mechanical properties of these soccer cleats, it seems that the relationship between shoe friction and knee moments are not consistent.

The observed similarity between Copa and World cleats during the vcut are in accord with Majid and Bader(1993), who, with earlier models of the Copa Mundial and World Cup cleats, used a weighted pendulum test apparatus to measure the amount of rotation occurring in these soccer shoes for a given input energy. They found that the Copa Mondial and World Cup cleats resulted in similar levels of axial rotation on natural grass, both of which were significantly different than the "Samba" flat rubber-soled shoe, designed for Astroturf. This is attributed to similar stud penetration between the Copa and World cleats into the turf sample (Majid & Bader, 1993). Stud penetration was not measured in this study.

The present study showed a dramatic increase in knee moments, and in particular, the external rotation and adduction moments between the running and v-cut trials. Although not the primary focus of this study, these results support the work of Besier et al.(2001), who reported transverse plane moments at the knee five times greater during cutting than running, and frontal plane moments between two and six times greater during cutting. These, however, were for barefoot trials through four different motions in order to evaluate the effect of the movement on knee loads. Furthermore, we found approximately 40-50% of standard deviation of transverse and frontal knee moments during the selected movement in this study. However, more than 50% of variation of knee ab/adduction and rotational moments often observed in the previous studies (Besier et al., 2001; Park et al., 2009).

Here, the increases were greater from running to v-cut motions than those observed by Besier et al.(2001), with the Copa and World cleats having higher moments than the Nova runner and Trx cleat during v-cut. Stefanyshyn(2003) proposed that increases in knee joint loading in the transverse and frontal planes (internal/external rotation, and ab/adduction, respectively) are associated with increased pain in the knee during running. These higher moments may produce greater stresses in the knee structures, leaving the joint more susceptible to overuse injuries (Stefanyshyn, 2003). If the forces are excessive, micro- or macrotraumas to various tissues surrounding the knee may be produced (Nigg & Segesser, 1988). In terms of acute injury, the higher moments observed in the Copa and World cleats would most likely result in a reduced margin of error between joint loading and the ultimate limits of the knee ligaments. Thus, there would be an increased risk of serious injury of the knee in the event of unplanned motions or perturbations.

The approach runway was comprised of regular artificial turf of 25mm thickness, while the force plate was covered with a 50mm-thick piece of rubber and sand infilled turf. Due to material limitations, a consistent runway of infilled turf was unavailable. As such, the neuromuscular adjustments made while stepping on the force plate constitute a possible confounder.

Subjects were allowed to chose an appropriate rest time between trials, however most performed the trials in a continuous manner, preferring to finish as soon as possible. Therefore, fatigue may have played a role in later trials.

V. Conclusion

It was found that soccer cleat design influences extension moments of the knee during running, and external rotation and adduction moments during a v-cut maneuver. These differences may lead to increased stresses on the knee, and ultimately, increased knee injury rates. It would be required to investigate the relationship between the mechanical properties of the soccer cleats and joint loading during movement.

Acknowledgements

We thank Luke Savage for helping with data collection and preparing the manuscripts, and Adidas International for providing testing shoes.

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투 고 일 : 04월 30일
심 사 일 : 05월 25일
심사완료일 : 06월 20일