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Knee Joint Moment during Golf Swing, Drop-landing, and Cutting Maneuver

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Abstract : The purpose of this study was to assess knee joint loading in the target knee during a golf swing compared to loading rates of high impact activities such as cutting and drop landings. Nine healthy competitive golfers completed golf swings with the target foot both straight and externally rotated 30 degrees, as well as drop landings and cutting maneuvers. Motion capture data was collected at 240 Hz and ground reaction force data was collected at 2400 Hz. The frontal and transverse knee moments were examined using repeated measures ANOVA through SPSS. The abduction moments were higher in golf swings as compared to the other high impact activities ($p=.010$), while the external rotation moments were lower ($p=.003$). There were no significant differences between externally rotated and neutral golf swings. These results suggest moments applied to the knee during a golf swing are similar to those applied during a high impact activity.

Keywords : Knee, Moment, Golf Swing, Drop-Landing, Cutting

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1. Introduction

Golf has become known as a sport for all ages. The benefits of such a sport and remaining active into the later years of life have been well documented; however, such benefits desist upon the occurrence of an injury. Therefore, it is important to be able to avoid injuries in lifetime sports such as golf that could inhibit the continuation of a healthy lifestyle. One particular injury type of concern is degenerative conditions of the knee. A better understanding of knee mechanical loading is needed to help comprehend the mechanisms that lead to lower-extremity overuse injuries in golfers.

Although golf has traditionally been considered a low-impact and low-risk sport, the prevalence of injuries is problematic. While lower extremity injuries (18%) and knee injury (7%) are less common than those to the elbows, and shoulders (53%), the presence of such injuries indicates that excessive loading may be occurring specifically at the knee of the target foot[1]. This claim is further supported by the increased amount of injuries that occur in elite golfers compared to amateurs[1]. The increase in injuries in the lower extremity for elite golfers suggests that the loads experienced by joints such as the knee are amplified[2].

Despite the increase in injury rates between skill levels, no differences in kinetics have been found between elite and amateur golfers[2]. The differences may occur, then, as a result of load with respect to use. Elite golfers may spend multiple hours a day in practice compared to amateur golfers who may play a couple times per week. The cumulative effect of the multiple loads may be to blame for the increased injury rates in the target knee. Determining the extent of loading is important in quantifying the injury risk of degenerative and chronic injury to the knee as a result of the load placed upon it during a golf swing.

In order to quantify the injury risk, the load placed upon the knee during a golf swing can be compared to the load that would be placed upon the knee during other high impact activities such as a cutting maneuver and drop-landing task. Specific comparisons of interest would be knee moments in the frontal and transverse planes. While frontal-plane knee joint moments during golf swing were found to be higher than some daily activities, transverse knee moments have yet to be determined[3]. Additionally, the broadening of knee overuse and degenerative conditions has been linked to alterations in frontal plane knee moment[4-7].

Differences in knee moment during a golf swing may occur due to set up position. It has been recommended as a fundamental skill for golfing to address the ball with an externally rotated target foot. Research indicates that the positioning of the target foot may influence the knee joint loading[8].

Therefore, the goal of this study is to quantify the peak internal and external rotation knee moments as well as the abduction and adduction moments on the target knee of elite golfers during the golf swing either 30° externally rotated or in a neutral foot position. It is hypothesized that the frontal-plane knee moments during golf swings would be similar to those during drop-landing but smaller than those during a cutting maneuver, and that the knee moments in the transverse plane during a golf swing would be greater than those during both the drop-landing and cutting. It is also hypothesized that externally rotating the target foot would result in a reduction of frontal and transverse plane knee moments and a decrease of mechanical loadings in the knee during a golf swing. Information obtained from this study could help researchers identify the risk of overuse knee conditions associated with golfers and help coaches develop modified swing techniques to reduce the risk of injury.

2. Methods

2.1. Participants

Nine healthy competitive golfers, 7 female (age: 20.00±1.15 years, height: 1.69±.03 meters, body wight: 61.26±6.75 kg, carrier: 4.50±0.96 years) and 2 male (age: 21.00±0.00 years, height: 1.81±.140 meters, body wight: 77.85±18.87 kg, carrier: 4.50±1.50 years) were recruited for this study. Additionally, participants must not have had any history of knee injury to either leg that may have resulted in knee motion adaption or any lower extremity musculoskeletal injury within the past twelve months. Before participating, each subject read and signed an informed consent form and completed a health history questionnaire.

2.2. Procedure

Each subject had a modified plug-in gait model marker set, including both upper and lower extremity markers, placed on anatomical landmarks to be used with a 12 camera VICON motion capture system collecting at 240 Hz (Vicon, Los Angeles, CA, USA). Four additional retro-reflective markers were placed on the golf club at the head, base of shaft, handle, and toe. Following an individualized golf warm-up consisting of practice golf swings and walking, each subject completed five golf swings using a 7-iron with the target foot in a neutral/straight position, five golf swings with the target foot 30° externally rotated, five drop landings from 80% of maximal jump height[9], five cuts at a 45° angle to right, as well as five cuts at a 45° angle to the left[10]. During the collection, two AMTI force plates were used to monitor the ground reaction forces under the feet while collecting at 2400 Hz (AMTI, Inc., Watertown, MA, USA). For all activities the same standard athletic footwear was used, except for during the golf swings in which participants wore their own golf shoes as artificial turf covered the force plates. A net was used to allow the indoor collection of golf swings. For the purposes of the golf swings, tape lines were placed on the artificial turf with one line to show the location for the neutral foot placement and the other line at a 30° externally rotated angle[8].

Five trials were collected and averaged for each activity using Vicon Nexus version 1.8.3 (Vicon Inc., Denver, CO, USA) and Visual 3D version 5 (C-Motion Inc., Rockville, MD, USA) to process the data. Position data was filtered using a fourth-order Butterworth filter with a cut off frequency of 8Hz. Ground reaction force data was filtered using a fourth-order low-pass Butterworth filter at 50 Hz.

2.3. Statistical analysis

All data was analyzed using repeated measures ANOVA in SPSS version 19 for Windows (SPSS Inc., Chicago, IL, USA). Statistical significance was set at $p<0.05$. Primary variables included knee moments in both the frontal and transverse planes.

3. Results & Discussion

Table 1 shows the measured target knee moments for both neutral and externally rotated golf swings as well as for cutting and drop-landing. Alteration of foot position from a neutral to an externally rotated position during the golf swing had no significant effect on target knee moment in either the transverse or frontal planes. As a result, the given p-values express the probability of difference in cutting or drop-landing to a neutral foot position during a golf swing rather than to each of the two golf swing foot positions.

Peak target knee abduction moment was greater than the moments for both drop-landing ($p=.010$) and cutting ($p=.012$). Peak target knee adduction for both golf swings was not significantly different from those during drop-landing ($p=.229$) but was

Table 1. Knee moment during golf swing, drop-landing, and cutting Unit: N/m

Moments	NGS	ERGS	Drop-landing	Cutting	η^2
Abduction	.608±.237*	.611±.225*	.209±.208	.351±.281	.524
Adduction	-.650±.234	-.642±.191	-.795±.369	-1.149±.457*	.534
Externally Rotated	.262±.098	.258±.084	.389±.137*	.567±.229*	.671
Internally Rotated	-.071±.097	-.060±.111	-.164±.136	-.466±.212*	.708

p<.05, significant difference from non-marked
NGS: Neutral Golf Stance, ERGS: Externally Rotated Golf Stance

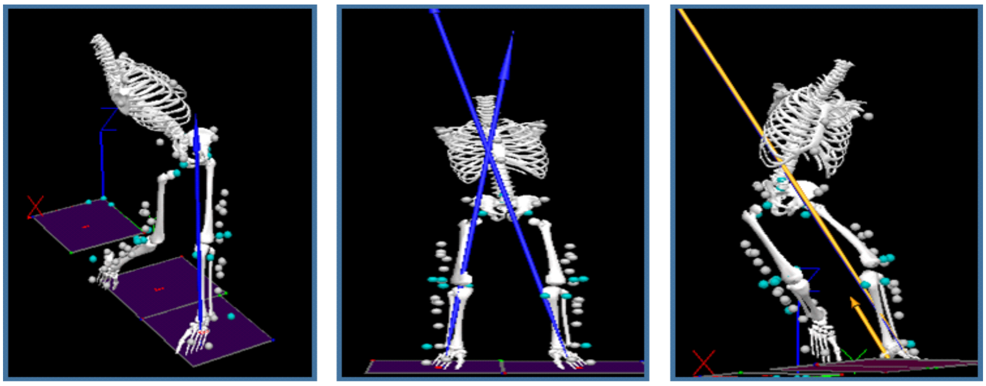

Fig. 1. The position of the ground reaction force of golf swing, drop-landing, and cutting maneuver.

significantly smaller than those during a cutting maneuver (p=.026) as hypothesized.

In the transverse plane, external rotation moment of the target knee was significantly less than the moments in both drop-landing (p=.004) and cutting (p=.003) contrary to what was hypothesized. Internal rotation moment for the two golf swings was not significantly different from the drop-landing moments (p=.147), but was significantly less than cutting (p=.001).

The main findings of this study are that in both the frontal and transverse planes the knee moments in golf swings are similar to, or, in some instances, such as knee abduction moment, greater than those associated with high impact activities such as cutting and drop-landing. While the broadening of knee overuse and degenerative conditions has been linked to alteration in frontal plane knee moment, these findings may also implicate moments in the transverse plane and further call into question the label of golf as a non-impact sport suitable for all ages due to the high amounts of loading seen in the knee.

The link of the frontal plane to the expansion of overuse knee injuries is supported by our finding that knee abduction moment is higher in golf swings than some high impact activities, namely cutting and drop-landings. Our findings further support the findings of Lynn[8], and Costigan[11], which identified the abduction moments of the target knee of a golf swing to be higher than walking and stair climbing. The increased load on the medial compartment of knee given by the large abduction moment can be compensated for by the relatively large surface area given to disperse the load throughout the cartilage[12]; for individuals with a propensity toward medial knee pain, movements such as golf swings may aggravate or initiate a more serious condition.

The knee adduction moment also showed moments for the target knee of a golf swing to be similar to those in a drop-landing and cutting maneuver. Unlike the knee abduction moment, which affects the medial compartment of the knee, a large surface area is not available to dissipate the load due to the decreased size of the lateral knee compartment. The total amount of loading experienced by the knee may not be enough to initiate a degenerative or overuse knee condition, but thought should be given before starting activity considering the anatomical implications. For a younger, non-elite population, the total frequency of loading cycles that would be experienced during golfing may not be enough to suggest the development of a degenerative knee condition. This seems to be maintained by the larger injury rates seen in the knees of a professional golfing population, as well as findings showing no significant differences between the kinetics of a golf swing for a non-elite and elite population[2]. As the number of loads increases so does the amount of injuries.

This factor can be further seen by evaluating the direction of the ground reaction force vector throughout the movement. Usually when the foot is in contact with the ground during a maneuver such as walking, cutting, or performing a drop-landing, the ground reaction force is directed medially to the axis of rotation causing a knee adduction moment[11]; acommon occurrence in everyday life, so the body is well equipped to respond to such loading. During a golf swing, the ground reaction force vector is directed laterally to the axis of rotation during the address, all the way until ball contact, and then shifts medially following ball contact[8]. Figure 1 demonstrate the similarities in the medial alignment of the ground reaction force between the three tested activities, and visually illustrate the source of the large adduction moment. The large abduction and adduction moments are seen during these time points; However, the adduction moment is a less anatomically efficient moment to dissipate because of the structure of the lateral knee, so the increased prevalence of Osteoarthritis in the lateral aspect of the knee[13] can be expected due to the surface area distribution about the knee. Another factor to consider is the effect of the large abduction and adduction moments on the musculature of the knee. Drop-landing and cutting maneuvers have been shown to be indicative of a high number of ACL tears from both contact and non-contact[14, 15].

One cause is thought to be the high abduction moment associated with each of these maneuvers. While a golf-swing may not happen as fast or as frequently as a drop-landing or cutting maneuver, the presence of a higher abduction moment during a golf swing than drop-landing or cutting may indicate a lasting negative effect on the ACL. Overtime the load may weaken the overall strength of the ligament.

Unlike the frontal plane, little has been done to quantify the moments during a golf swing in the transverse plane. While our study found the external rotation moment to be lower than both drop-landing and cutting, the internal rotation moment was similar to the load seen in a drop-landing maneuver. Like abduction moment, an increase in internal rotation moment is associated with increased strain on the ACL[14, 16]. In a study by Shin et al. which tested ACL strain during single-leg landings, an increase in internal rotation moment elicited higher strain on the ACL; the same finding held true for an increase in abduction moment. Additionally, the combination of increased internal rotation and abduction moment created the highest strain on the ACL[16]. During a golf swing both the internal rotation moment and the abduction moment are similar to those found in drop-landings, which are associated with a high prevalence of ACL tears[14]. Additionally, an internal rotation moment is largely dissipated by the posterior-lateral side of the tibia[16]. As previously stated, the lateral compartment of the knee is less suitable to disperse a load due to the decrease in surface area. The combination of the increased strainand the location of application indicate that a golf swing may, if completed over several years, be indicative of ACL weakening or damage.

Contrary to our hypothesis based on previous studies, externally rotating the foot during the golf swing did not alter knee moments[8]. The lack of difference may have been due to the differences in method. Our method utilized turf over the force plate, golf shoes, and swing ing to hit a golf ball. In contrast, the study that found significant differences with an externally rotated foot position used athletic shoes, no turf, and no golf ball. Our setup is more relatable to an actual golf game. Our finding also appears to support the diversity of foot position while golfing as seen in professional and amateur golfers alike. It appears that selecting a different foot position does not alter knee loading. This finding may alleviate concerns for golfers who may have felt pressured to alter foot position from their preferred golfing setup. Future studies should further investigate swing mechanics between these two foot positions during a golf swing to determine the differences in knee joint moments. Future studies should also focus on examining knee contact forces during a golf swing using modeling techniques.

4. Conclusion

This data suggests that professional golfers generate comparable knee mechanical loading to other high impact activities such as cutting and drop-landing in the frontal and transverse planes. This suggests that the mechanisms of injury during a golf swing may be similar to those found in higher impact activities. It also gives better understanding to the large number of knee overuse injuries exhibited in professional golfers. Medical professionals should consider the high joint loading associated with golfing before recommending golf to patients, especially to those with a propensity toward knee overuse and degenerative conditions as well as prior ACL damage.

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