KJSB

Korean Journal of Sport Biomechanics 2018; 28(4): 199-205
http://dx.doi.org/10.5103/KJSB.2018.28.4.199
http://e-kjsb.org eISSN 2093-9752

ORIGINAL

Anterior Cruciate Ligament Injury is Unlikely to Occur when Performing a Stable Weight Lifting Operation

Youngjin Moon[1], Jeheon Moon[2]

[1]Department of Sports Science, Chungnam National University, Daejeon, South Korea
[2]Department of Sports Science, Korea Institute of Sport Science, Korea Sports Promotion Foundation, Seoul, South Korea

Received : 09 December 2018
Revised : 17 December 2018
Accepted : 21 December 2018

Corresponding Author
Jeheon Moon
Department of Sports Science,
Korea Institute of Sport Science,
727 Hwarang-ro, Nowon-Gu,
Seoul, 01794, South Korea
Tel : +82-2-970-9544
Fax : +82-2-970-9686
Email : jhmoon@kspo.or.kr

Objective: The purpose of this study was to examine the effect of increase in barbell weight on closely related variable to the anterior cruciate ligament (ACL) injury which are knee joint kinematics, joint load, joint moment, and maximum load attainment point during snatch of the weight lifting.

Method: The subjects of the study were 10 male Korean national weight lifting athletes (69 kg 5, 77 kg 5; age: 21.80±3.91 yrs., height: 168.00±4.06 cm, weight: 75.00±4.02 kg, career: 7.8±3.99 yrs., snatch records: 168± 4.06 kg). The weight of the barbell during the snatch operation was set at 70%, 75% and 80% of the highest records for each subject studied.

Results: The result obtained from the one-way repeated measure ANOVA are as follows: With increased barbell weight, the extension moment of the left knee joint was higher in the 80% condition than the 70% ($p<.001$). However, other variables were not statistically significant difference. According to the factor analysis of the variables related to maximum load attainment point of the ACL major injury variables, the first sub-factor was the internal shear force, the posterior shear force, the abduction moment, and the muscle activity of the VL. The second sub-factor was the extension moment of the knee joint, compressive force, adduction moment, and the third sub-factor was the muscle activity of BF.

Conclusion: These results indicate that the possibility of ACL injury can be lowered when performing a stable snatch movement.

Keywords: Weight lifting, Snatch, ACL injury, Knee load

INTRODUCTION

Weight lifting is a sport that constantly pursues challenges to human limitations. Especially in weight lifting, an injury is likely to occur due to a wrong operation or mistake in instantaneous judgment when lifting the barbell raised over the head with heavy weights (Moon, 2014). The body injury areas surveyed for elite weightlifters were reported in order of 0.71/1,000 hours, 0.41/1,000 hours for lumbar spine, 0.33/1,000 hours for knee joints, elbow, and 0.18/1,000 hours (Raske & Norlin, 2002). A similar study showed that the body parts with highest frequency of injuries were 36% in the shoulder region, 24% in the lumbar spine region, 11% in the elbow region, and 9% around the knee joint and depending on the type of injuries were sudden injury accounted for 59% (Keogh, Hume, & Rearson, 2006). In particular, it has been reported that high load acts on the knee joint accompanied by an unbalanced muscle activity of the rectus femoris (RF) and bicep femoris (BF) which may results in anterior cruciate ligament (ACL) injury (DeMorat, Weinhold, Blackburn, Chudik, & Garrett, 2004; Hewett et al., 2005; McLean, Huang, & Bogert, 2008; Seering, Piziali, Nagel, & Schurman, 1980, Shin, Chaudhari, & Andriacchi, 2007).

Most ACL injuries are noncontact injuries with no physical contact where knee injuries account for almost 70% of all injuries (Bere et al., 2011; Boden, Dean, Feagin, & Garrett, 2000; Koga et al., 2010). Majewski, Susanne and Klaus (2006) conducted a survey of 7,769 knee joint injuries during sports activities for 10 years where 44.82% were due to internal shock and 33.88% due to internal rotation. Out of 3,482 cases of structural abnormality, 1,580 cases were caused by internal rotation shock in which 45.38% of them had injuries related to the ACLs. However, studies on ACL injuries have shown that the injuries are caused by internal rotation and twisting, as well as anterior shearing force along with the strong muscle contraction of the femoral muscles (Fukuda et al., 2003; McLean, Huang, Su, & Bogert, 2004; McLean et al., 2008; Yu & Garrett, 2007).

Weightlifting motion is characterized by the large external rotation moment of the knee joint during the lifting section of the barbell and a high tibial shear force due to the weight of the competitor and the load of the barbell (Lorenzetti et al., 2012; Moon, Kwon, & Lee, 2011; Schoenfeld, 2010). In addition, players with BF muscle's injury experience are likely to suffer secondary damage, such as ACL injuries due to strong RF contractions in last pool operations, as the ratio of RF to BF showed

Copyright © 2018 Korean Journal of Sport Biomechanics
This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/3.0/) which permits unrestricted noncommercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

an unbalanced pattern compared to other weightlifters (Moon, 2014, 2015). Therefore, it is necessary to research the possibility of ACL injuries and clarify the mechanism of injury by performing lifting operation where a high weighted barbell is lifted above the head. The purpose of this study was to analyze the possibility of ACL injury i.e. change in moment and load of the knee joints when increasing the weight of the barbell, and also to ascertain maximum load attainment point (T_{peak}) of the major biomechanical factors that increase the ACL load.

METHOD

1. Participants

We recruited 10 participants affiliated to Korean national weightlifting team (69 kg: 5 male and 77 kg: 5 male) who had an average age of 21.8±3.91 years old, 168.0±4.06 cm in height, 75.0±4.02 kg in weight, 7.8±3.99 years in athletic career, and highest weightlifting record of 168±4.06 kg. The athletes participating in this study regularly participate in weightlifting competitions and all have won first place in national competitions. The participants reported no history of pathological abnormalities or injuries to the musculoskeletal system, including knee joints, during the past six months. All participants read the research guide, signed the consent form and participated in the experiment voluntarily and were approved by the Bio-Research Ethics Committee of the Korea Institute of Sport Science (KISS-201511-IFS-034-P1).

2. Procedures

All experiments were conducted at the same place and time, and the room temperature was set at 23℃ using an indoor air conditioner. The schedule of the experiment was finalized a month ago after consultation with the subjects and their coaches, and were asked to perform 80% of their highest weightlifting record. Here, 80% weight was considered to be the highest weight that a subject can perform in laboratory setting based on their physical condition at the time of experiment.

The subjects who participated in this study were first informed about the purpose of the study, the process of experiment, and the protection of personal information verbally and signed the consent form.

The reflective markers required for motion analysis consisted of joint markers attached to the main joints of the body and tracking markers attached to three or more segments (Cappozzo, Cappello, Croce, & Pensalfini, 1997; Collins, Ghoussayni, Ewins, & Kent, 2009; Wu et al., 2005). The reflective markers were attached to the major joints and segments after wearing the experimental suit provided by the experimenter. The electromyography (EMG) sensors were then attached on the thighs muscles i.e. to the vastus lateralis (VL) and BF. One of the muscles affecting the ACL load is the RF however VL was measured in place of the RF because the position of EMG sensors affected the movement of the bar when performing the pulling motion. After all the preparations were completed, 30 minutes period was given for stretching and lifting low-barbell weights to minimize the risk of injury.

The athletes who were ready after the warm-up had their static posture capture in an anatomical posture for 5 seconds to estimate the center of mass (COM) of the human body. Afterwards, a total of eight reflective markers were removed from the left and right elbow, wrist, knee and ankle. Where by, two force plates were used to assess the ground reaction force during the weight lifting motion. The weights of the barbell were set at 70%, 75%, and 80% of the personal best of each subject studied. Out of the three trials performed, only those data that the athlete and the leader considered the most desirable actions were used for the analysis. In the experiment there was a gradual increase in the barbell weight and five minute break was provided between each trial to rule out the effect of the difference in strength due to fatigue (Whitting, Meir, Crowley-McHattan, & Holding, 2016).

A three dimensional kinematic analysis was conducted using Qualisys infrared camera system (Oqus 7+, AB, Gothenburg, Sweden) at the sampling frequency of 120 Hz. The ground reaction force was calculated using Kistler force plates Type 9287BA, AG, Winterthur, Switzerland) at sampling frequency of 1,200 Hz. Similarly, Noraxon EMG system (DTS, Scottsdale, AZ, USA) was used to assess the muscle activation at sampling frequency of 1,500 Hz.

3. Data processing

In order to remove the noise included in the measurement, the Butterworth 4th order low-pass filter at cut-off frequency of 4 Hz was applied to the motion data (Hadi, Akkus, & Harbili, 2012; Whitting et al., 2016). The signal obtained by the force plate was filtered with a Butterworth 4th order low-pass filter at cut-off frequency of 50 Hz (Whitting et al., 2016). For the raw EMG signals the following procedure was used to filter the data.: the Butterworth high-pass filter at cut-off frequency of 10 Hz, Butterworth low-pass filter at cut-off frequency of 300 Hz, rectified, and then, smoothed over 250 milliseconds (root means square algorithm) (Rønnestad, Holden, Samnøy, & Paulsen, 2012).

The range of motion (ROM) of the knee joint and the maximum angular velocity corresponding to the kinematic variables were calculated by the Cardan sequence method using 3D marker coordinates. The flexion / extension movement of the knee joint was set to the x axis, the abduction / abduction was set to the y axis, and the internal/external rotation was set to the z axis. The femur was defined as reference based on the lower limb. An inverse dynamics method was used to calculate the load and moment of the knee joint. The internal and external loads of the knee joint were defined as the x-axis, the anterior / posterior as the y-axis, and the superior / inferior as the z-axis. The Visual3d software (version 5.01, C-Motion Inc., Rockville, MD, USA) was used to calculate the range of motion, maximum angular velocity, shear force and moment variables of the knee joint. The T_{peak} factor affecting the ACL injury was calculated using Matlab (ver. R2009b, The MathWorks, Inc., Natick, MA, USA).

4. Statistical analysis

A one-way ANOVA of repeated measurements was performed to analyze the differences in the dependent variables (ROM, angular velocity, load, moment) according to the increase in the barbell weight (70%, 75%, and 80%). If a statistically significant difference was observed, post-hoc analysis was used to confirm the difference between the samples and the significance level was set to $p<.017$. Similarly, Factor analysis was performed to identify the T_{peak} components for major ACL injury. Factor extraction was based on principal component and varimax rotation was performed. All statistical analyzes were performed using SPSS 18.0 (SPSS, Inc., Chicago, IL, USA).

RESULTS

There was no statistically significant difference in the ROM of the knee joint and the maximum angular velocity according to the weight of the barbell at 70%, 75%, and 80% of the personal best (Table 1). In addition, there was no statistically significant difference in the load normalized to the weight of the knee joint acting on medial, posterior, and inferior direction. The knee extension moment was 211.6 Nm at 80% weight, which was higher than 183.4 Nm of 70% weight ($p<.001$). The normalized extension moment of 80% weight was higher than 70% ($p<.001$). There were no statistical difference in other variables related to moment.

Factor analysis showed that the load, moment, VL and RF muscle

Table 1. Results of One- way repeated measure ANOVA of factors influencing the Knee joint with the increase in load. Mean ± SD

Variables (unit)	70%		75%		80%	
	Right	Left	Right	Left	Right	Left
ROMof knee (°)						
Sagittal plane	140.7±9.8	147.7±8.7	141.5±9.4	148.4±11.3	143.1±6.8	150.9±11.4
Frontal plane	38.8±4.2	39.1±8.3	38.4±4.8	38.5±8.6	38.7±5.4	40.4±10.7
Transverse plane	40.0±11.7	38.7±10.4	43.1±11.4	39.0±7.6	45.1±13.4	41.1±9.9
ROM of knee AV (°/sec)						
Sagittal plane	492.9±57.8	510.2±54.4	499.2±51.5	520.9±53.5	491.7±54.8	510.5±75.5
Frontal plane	147.9±58.7	131.3±28.7	151.8±67.2	126.5±49.9	139.2±53.8	127.4±45.7
Transverse plane	182.2±72.5	181.3±53.0	189.6±60.2	200.7±47.4	189.7±46.0	209.6±77.7
Maximum knee force (N)						
Medial	445.5±114.3	456.9±173.3	454.7±116.0	472.6±182.3	476.1±132.1	477.2±187.2
Posterior	901.3±140.8	932.0±118.0	918.8±134.7	956.2±108.5	934.8±154.1	963.1±118.9
Distal	1090.5±132.9	1111.7±104.9	1106.7±125.4	1150.2±126.5	1137.6±129.9	1192.1±137.1
Maximum knee moment (Nm)						
Extension	146.5±22.1	183.4±40.6	154.6±30.1	184.3±45.5	176.5±34.0	211.6±44.7*
Abduction	80.2±28.3	66.7±20.1	81.9±34.6	64.5±22.1	86.3±33.9	68.9±22.6
Adduction	116.6±23.7	130.1±40.9	118.7±25.7	135.3±37.6	134.5±25.1	147.5±37.7
External rotation	46.6±10.3	26.9±12.9	46.4±11.9	26.1±13.2	49.2±12.8	27.9±13.6
Normalized maximum knee force (Nm/BW)						
Medial	0.59±0.15	0.60±0.23	0.60±0.15	0.63±0.24	0.63±0.17	0.63±0.25
Posterior	1.19±0.19	1.23±0.16	1.22±0.18	1.27±0.14	1.24±0.20	1.27±0.16
Distal	1.44±0.18	1.47±0.14	1.47±0.17	1.52±0.17	1.51±0.17	1.58±0.18
Normalized maximum knee moment (Nm/(BW*HT))						
Extension	0.012±0.001	0.015±0.003	0.012±0.002	0.015±0.003	0.014±0.003	0.017±0.004*
Abduction	0.006±0.002	0.005±0.002	0.007±0.003	0.005±0.002	0.007±0.003	0.006±0.002
Adduction	0.009±0.002	0.010±0.004	0.010±0.003	0.011±0.003	0.011±0.002	0.012±0.004
External rotation	0.004±0.001	0.002±0.001	0.004±0.001	0.002±0.001	0.004±0.001	0.002±0.001

ROM = range of motion, AV = angular velocity, BW = body weight, HT = height
*Significant load main effect-post hoc comparison showing a maximum knee extension moment for 70% vs. 80% ($p<.001$)

Table 2. The result of maximum load attainment point (T_{peak}) and factor analysis of the joint force, moment, and muscle activation of the knee joint at 80% of the personal best

Variables	Time (sec)	Factor 1	Factor 2	Factor 3
Medial shear force	0.035±0.028	0.899	0.241	0.02
Posterior shear force	0.021±0.025	0.803	0.32	0.288
Abduction moment	0.362±0.068	0.782	0.091	0.001
Vastus lateralis activation	0.448±0.166	0.403	0.394	0.383
Extension moment	1.175±0.253	0.153	0.897	-0.095
Compressive force	0.573±0.037	0.182	0.814	-0.048
Adduction moment	1.378±0.220	0.241	0.667	0.585
Biceps femoris activation	0.865±0.294	-0.118	-0.031	0.816
Lateral rotation moment	0.431±0.115	0.329	-0.088	0.509
Rotation Sums of Squared Loadings Total		2.463	2.244	1.508
% of Variance		27.365	24.935	16.755
Cumulative %		27.365	52.3	69.055

KMO = .661, Bartlett's test result χ^2 = 66.509, $p<.001$

activity of the knee joint, which are related to the ACL injury at the 80% (Table 2). According to the validity analysis of the dependent variables, the KMO value was .661 and the probability of Bartlett's sphere formation test was less than $p<.001$. As a result of factor analysis, maximum load attainment point of ACL injury factor was composed of three multi-dimensional sub-factors. The first sub-factor consisted of the internal shear force, the posterior shear force, the abduction moment, the muscle activity of the VL and the factor loadings ranged from .403 to .899. The second sub-factor was composed of the extension moment of the knee joint, compressive force, and adduction moment. The factor loadings was .667-.897. The third sub-factor was the BF muscle activity, and the lateral load moment of the knee joint was .509~.816. Therefore, in case of weightlifting, the T_{peak} which corresponds to be a major ACL injury variables appeared at three different time points.

DISCUSSION

A typical kinematical factor in an ACL injury is the shear force of the knee joint, the abduction and the moment of rotation, and the strong muscular contraction of the femur muscle (Berns, Hull, & Patterson, 1992; DeMorat et al., 2004; Markolf et al., 1995). Events such as weightlifting need to consider factors that affect ACL injuries because of the high strains that intersect around the knee joints when lifting heavy weights. In order to achieve the purpose of the study, we analyzed the load, moment, VL and BF muscle activity of the knee joints by increasing barbell weight, but no statistically significant difference between weights were noted, except for the extension moment of the left knee joint.

The shear force acting on the tibia is known to be a strong factor in increasing ACL load (Bere et al., 2011; Berns et al., 1992; Boden et al., 2000). According to the results of this study, the maximum medial shear force of the left and right knee joints was 477.2 N and the maximum posterior shear force was 963.1 N which was up to the personal best weight of 70%, 75%, and 80%. This value is significantly lower than 2,000 N reported as the threshold level of ACL injury by knee joint shear (McLean et al., 2008; Seering et al., 1980; Shin et al., 2007). Also, there was no statistical difference with the increase in the barbell weight. Therefore, the possibility of ACL injuries due to knee joint shear force at 70, 75, and 80% barbell weights is low.

In order to evaluate the risk factors for ACL injury, consideration should be given to moment factors acting in the direction of abduction as well as knee joint shear forces. Many previous studies have reported that the abduction moment of the knee joint is a major factor which affects the ACL load to increase (Fukuda et al., 2003; Hollis, Takai, Adams, Horibe, & Woo, 1991; Markolf et al., 1995; McLean et al., 2004; McLean et al., 2008). Here, the threshold level of occurrence of ACL injuries is considered to be more than 125 Nm (McLean et al., 2008; Seering et al., 1980; Shin et al., 2007). According to the results of this study, the maximum abduction moment of the knee joint was 86.3 Nm during the first pool period when performing the weight lifting operation. The results were significantly lower than the injury threshold of the knee joint abduction moment presented by McLean et al. (2008), Seering et al. (19980), and Shin et al. (2007). In addition, since the tendency of the knee joint abduction moment does not increase even when the weight of the barbell is increased, the possibility of ACL injury due to the abduction moment is expected to be low in the weight lifting.

The internal rotation moment acting on the knee joints is reported to be a major factor in increasing ACL load (Berns et al., 1992; Markolf et al., 1995). Markolf et al. (1995) observed ACL loads after applying 100 N shear force and 10 Nm internal or external rotation moment to the cadaveric knees. As a result, the ACL force was reported to be at approximately 180 N which is 2.6 times higher than the 70 N condition when combined load of the shear force and the internal rotation moment

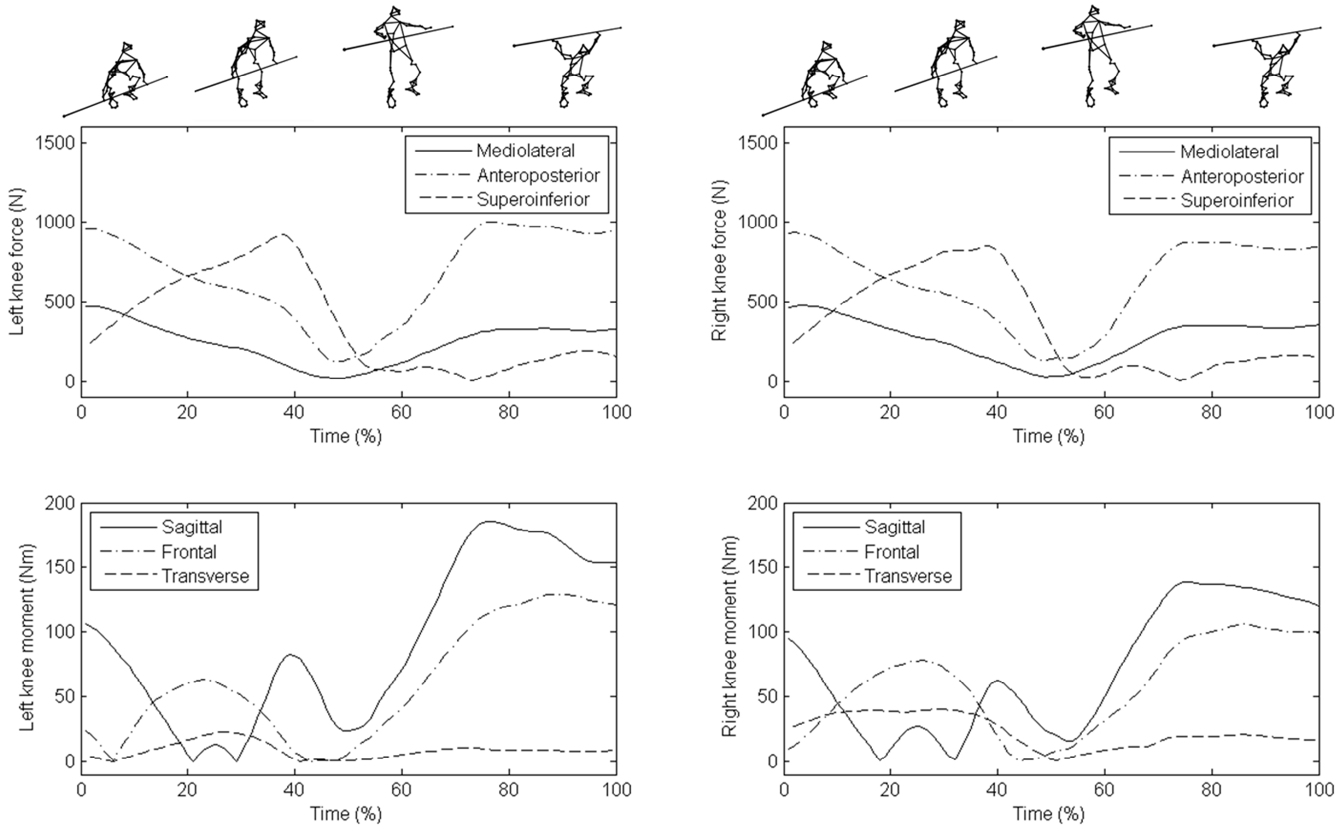

Figure 1. Change in load and moment of the left and right knee joints normalized by time of 80% personal best (n = 10).

was applied to the knee joint at 15° knee flexion. Based on the results of the previous study, we studied ACL injuries with an emphasis on the internal rotation moment rather than the external rotation moment (McLean et al., 2004; Weinhandl et al., 2013). According to the results of our study, the internal rotation moment was not observed during the lifting operation, but the external rotation moment was high. The maximum value of the external rotation moment is less than 50 Nm, which is lower than 71 Nm reported during directional changing movement (McLean et al., 2004). In addition, the increase of the barbell weight did not show the tendency of increasing the external rotation moment, which rules out the possibility of having significant affect in the increase of the ACL load.

The majority of ACL injuries are caused by a sudden change in speed and direction with landing (Kernozek & Ragan, 2008; Laughlin et al., 2011; Pflum, Shelburne, Torry, Decker, & Pandy, 2004), jump after stop (Lin et al., 2009), and cutting movement (McLean et al., 2004; McLean et al., 2008). It should also be noted that when testing the time to reach the injury from the actual sporting situation, ACL injuries are caused by a strong and diverse force in a short period of time of less than 0.04 sec (Koga et al., 2010; Olsen, Myklebust, Engebretsen, & Bahr, 2004). According to the results of factor analysis of the T_{peak} of the ACL injuries performed in this study, the first sub-factor consisted of shear force of knee joint, abduction moment, and muscle activity of VL. The time difference of the knee joint shear force, abduction, and VL muscle activity to reach their respective T_{peak} is 0.3 sec or more, indicating a significant time difference within the factor. Further, the ACL injury occurrence time of 0.04 sec suggested by Koga et al. (2010) and Olsen et al., 2004) also differed. The second sub factor was composed of extension and adduction moment of the knee joint and compressive force. However, the extension and adduction moments are not considered as a significant variable which increases the ACL load. Rather the compressive forces are interpreted as a factor that affects the ACL load to increase due to body weight (Shin et al., 2007; Withrow, Huston, Wojtys, & Ashton-Miller, 2006). However, the compressive force is composed of other sub-factors that are different from the variables related to the ACL injury risk such as shear force and abduction moment.

The third sub-factor consisted of BF muscle activity and lateral rotation moment of the knee joint (Table 2). It has been reported that BF has a role in reducing the ACL load on through co-contraction with the quadriceps muscle (Hewett et al., 2005; Kernozek & Ragan, 2008). However, the results of our factor analysis indicate that the T_{peak} of BF was composed of the third sub-factor together with the external rotation moment and was delayed about 0.4 second compared to T_{peak} of VL where the time-delayed characteristic of the co-contraction was observed. These results suggest that the effect of co-contraction of quadriceps femoris and BF should be considered from a different point of view on the reduction of ACL load. According to the results of factor analysis of T_{peak} of ACL injury, the load acting on the knee joint in a weight lifting motion is not concentrated at a single point (Figure 1). This suggests that the factors which causes ACL injury are likely to be distributed which may lower the possibility of injury.

CONCLUSION

The aim of our study was to analyze the possibility of ACL injury through change in moment and load of the knee joints with the increase in load in a weightlifting motion. We wanted to ascertain the T_{peak} of the major kinematic factors that increase the ACL load. Our study showed that, there was no statistical difference according to the increase of the barbell in the variables other than the extension moment of the left knee joint. In addition, since the T_{peak} was not observe to be the similar, the possibility of ACL injury is considered to be low for the national team players if they have stable increases during training. Moreover, it is considered that even higher intensity will not be a problem. However, it is important to note that it is likely that the load will be concentrated on other body parts which may lead to an injury if the motion is unstable or the strength of a particular body specific region is weak.

ACKNOWLEDGEMENT

We thank the Korea Institute of Sport Science for providing financial support for this study.

REFERENCES

Bere, T., Flørenes, T. W., Krosshaug, T., Koga, H., Nordsletten, L., Irving, C., Muller, E., Cortas Reid, R., Senner, V. & Bahr, R. (2011). Mechanisms of anterior cruciate ligament injury in World Cup alpine skiing a systematic video analysis of 20 cases. *The American Journal of Sports Medicine*, *39*(7), 1421-1429.

Berns, G. S., Hull, M. L. & Patterson, H. A. (1992). Strain in the anteromedial bundle of the anterior cruciate ligament under combination loading. *Journal of Orthopaedic Research*, *10*(2), 167-176.

Boden, B. P., Dean, G. S., Feagin Jr, J. A. & Garrett Jr, W. E. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopedics*, *23*(6), 573-578.

Cappozzo, A., Cappello, A., Croce, U. D. & Pensalfini, F. (1997). Surface-Marker Cluster Design for 3-D Bone Movement Reconstruction. *IEEE Transactions on Biomedical Engineering*, *44*(12), 1165-1174.

Collins, T. D., Ghoussayni, S. N., Ewins, D. J. & Kent, J. A. (2009). A six degrees-of-freedom marker set for gait analysis: repeatability and comparison with a modified Helen Hayes set. *Gait & Posture*, *30*(2), 173-180, 2009.

DeMorat, G., Weinhold, P., Blackburn, T., Chudik, S. & Garrett, W. (2004). Aggressive quadriceps loading can induce noncontact anterior cruciate ligament injury. *The American Journal of Sports Medicine*, *32*(2), 477-483.

Fukuda, Y., Woo, S. L. Y., Loh, J. C., Tsuda, E., Tang, P., McMahon, P. J. & Debski, R. E. (2003). A quantitative analysis of valgus torque on the ACL: a human cadaveric study. *Journal of Orthopaedic Research*, *21*(6), 1107-1112.

Hadi, G., Akkus, H. & Harbili, E. (2012). Three-dimensional kinematic analysis of the snatch technique for lifting different barbell weights. *The Journal of Strength & Conditioning Research*, *26*(6), 1568-1576.

Hewett, T. 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. *The American Journal of Sports Medicine*, *33*(4), 492-501.

Hollis, J. M., Takai, S., Adams, D. J., Horibe, S. & Woo, S. Y. (1991). The effects of knee motion and external loading on the length of the anterior cruciate ligament (ACL): a kinematic study. *Journal of Biomechanical Engineering*, *113*(2), 208-214.

Keogh, J., Hume, P. A. & Pearson, S. (2006). Retrospective injury epidemiology of one hundred one competitive Oceania power lifters: the effects of age, body mass, competitive standard, and gender. *The Journal of Strength & Conditioning Research*, *20*(3), 672.

Kernozek, T. W. & Ragan, R. J. (2008). Estimation of anterior cruciate ligament tension from inverse dynamics data and electromyography in females during drop landing. *Clinical Biomechanics*, *23*(10), 1279-1286.

Koga, H., Nakamae, A., Shima, Y., Iwasa, J., Myklebust, G., Engebretsen, L., Bahr, R. & Krosshaug, T. (2010). Mechanisms for noncontact anterior cruciate ligament injuries knee joint kinematics in 10 injury situations from female team handball and basketball. *The American Journal of Sports Medicine*, *38*(11), 2218-2225.

Laughlin, W. A., Weinhandl, J. T., Kernozek, T. W., Cobb, S. C., Keenan, K. G. & O'Connor, K. M. (2011). The effects of single-leg landing technique on ACL loading. *Journal of Biomechanics*, *44*(10), 1845-1851.

Lin, C. F., Gross, M., Ji, C., Padua, D., Weinhold, P., Garrett, W. E. & Yu, B. (2009). A stochastic biomechanical model for risk and risk factors of non-contact anterior cruciate ligament injuries. *Journal of Biomechanics*, *42*(4), 418-423.

Lorenzetti, S., Gülay, T., Stoop, M., List, R., Gerber, H., Schellenberg, F. & Stüssi, E. (2012). Comparison of the angles and corresponding moments in the knee and hip during restricted and unrestricted squats. *The Journal of Strength & Conditioning Research*, *26*(10), 2829-2836.

Majewski, M., Susanne, H. & Klaus, S. (2006). Epidemiology of athletic knee injuries: a 10-year study. *The Knee*, *13*(3), 184-188.

Markolf, K. L., Burchfield, D. M., Shapiro, M. M., Shepard, M. F., Finerman, G. A. & Slauterbeck, J. L. (1995). Combined knee loading states that generate high anterior cruciate ligament forces. *Journal of Orthopaedic Research*, *13*(6), 930-935.

McLean, S. G., Huang, X., Su, A. & van den Bogert, A. J. (2004). Sagittal plane biomechanics cannot injure the ACL during sidestep cutting. *Clinical Biomechanics*, *19*(8), 828-838.

McLean, S. G., Huang, X. & van den Bogert, A. J. (2008). Investigating isolated neuromuscular control contributions to non-contact anterior cruciate ligament injury risk via computer simulation methods. *Clinical Biomechanics*, *23*(7), 926-936.

Moon, Y. J. (2016). Evaluation of Biomechanical Movements and Injury Risk Factors in Weight Lifting (Snatch). *Korean Journal of Sport*

Biomechanics, *26*(4), 369-375.

Moon, Y. J., Kwon, A. S. & Lee, G. S. (2011). Development and Kinematic Evaluation for Training Method to Strengthen Part Motion of Snatch in Weight Lifting. *Korean Journal of Sport Biomechanics*, *21*(2), 153-159.

Moon, Y. J. & Stefanyshyn, D. (2015). 3-Dimensional Performance Optimization Model of Snatch Weightlifting. *Korean Journal of Sport Biomechanics*, *25*(2), 157-165.

Olsen, O. E., Myklebust, G., Engebretsen, L. & Bahr, R. (2004). Injury mechanisms for anterior cruciate ligament injuries in team handball a systematic video analysis. *The American Journal of Sports Medicine*, *32*(4), 1002-1012.

Pflum, M. A., Shelburne, K. B., Torry, M. R., Decker, M. J. & Pandy, M. G. (2004). Model prediction of anterior cruciate ligament force during drop-landings. *Medicine and Science in Sports and Exercise*, *36*(11), 1949-1958.

Raske, Å. & Norlin, R. (2002). Injury incidence and prevalence among elite weight and power lifters. *The American Journal of Sports Medicine*, *30*(2), 248-256.

Rønnestad, B. R., Holden, G., Samnøy, L. E. & Paulsen, G. (2012). Acute effect of whole-body vibration on power, one-repetition maximum, and muscle activation in power lifters. *The Journal of Strength & Conditioning Research*, *26*(2), 531-539.

Schoenfeld, B. J. (2010). Squatting kinematics and kinetics and their application to exercise performance. *The Journal of Strength & Conditioning Research*, *24*(12), 3497-3506.

Seering, W. P., Piziali, R. L., Nagel, D. A. & Schurman, D. J. (1980). The function of the primary ligaments of the knee in varus-valgus and axial rotation. *Journal of biomechanics*, *13*(9), 785-794.

Shin, C. S., Chaudhari, A. M. & Andriacchi, T. P. (2007). The influence of deceleration forces on ACL strain during single-leg landing: a simulation study. *Journal of Biomechanics*, *40*(5), 1145-1152.

Weinhandl, J. T., Earl-Boehm, J. E., Ebersole, K. T., Huddleston, W. E., Armstrong, B. S. & O'Connor, K. M. (2013). Anticipatory effects on anterior cruciate ligament loading during sidestep cutting. *Clinical Biomechanics*, *28*(6), 655-663.

Whitting, J. W., Meir, R. A., Crowley-McHattan, Z. J. & Holding, R. C. (2016). Influence of footwear type on barbell back squat using 50, 70, and 90% of one repetition maximum: A biomechanical analysis. *The Journal of Strength & Conditioning Research*, *30*(4), 1085-1092.

Withrow, T. J., Huston, L. J., Wojtys, E. M. & Ashton-Miller, J. A. (2006). The relationship between quadriceps muscle force, knee flexion, and anterior cruciate ligament strain in an in vitro simulated jump landing. *The American Journal of Sports Medicine*, *34*(2), 269-274.

Wu, G., Van Der Helm, F. C., Veeger, H. D., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A. R., McQuade, K., Wang, X., Werner, F. W. & Buchholz, B. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. *Journal of Biomechanics*, *38*(5), 981-992.

Yu, B. & Garrett, W. E. (2007). Mechanisms of non-contact ACL injuries. *British Journal of Sports Medicine*, *41*(1), i47-i51.