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Kinematic and Kinetic Analysis of the Soft Golf Swing using Realistic 3D Modeling Based on 3D Motion Tracking

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Abstract

Kinematic and kinetic analysis has been performed for Soft Golf swings utilizing realistic three dimensional computer simulations based on three dimensional motion tracking data. Soft Golf is a newly developed recreational sport in South Korea aimed to become a safe and easy-to-learn sport for all ages. The advantage of Soft Golf stems from lighter weight of the club and much larger area of the sweet spot. This paper tries to look into kinematic and kinetic aspects of soft golf swings compared to regular golf swing and find the advantages of lighter Soft Golf clubs. For this purpose, swing motions of older aged participants were captured and kinematic analysis was performed for various kinematic parameters such as club head velocity, joint angular velocity, and joint range of motions as a pilot study. Kinetic analysis was performed by applying kinematic data to computer simulation models constructed from anthropometric database and the measurements from the participants. The simulations were solved using multi-body dynamics solver. Firstly, the kinematic parameters such as joint angles were obtained by solving inverse dynamics problem based on motion tracking data. Secondly, the kinetic parameters such as joint torques were obtained by solving control dynamics problem of making joint torque to follow pre-defined joint angle data. The results showed that mechanical loadings to major joints were reduced with lighter Soft Golf club.

Key words : soft golf, biomechanics, golf injury

I. INTRODUCTION

A new recreational sport game, Soft Golf, has been invented by Kim and Kim [1]. The recent designs of the clubs used in the game are shown in Fig. 1. The new game is played by hitting a small sized soft ball with a club that has similar length of regular golf but has a small tennis racquet shaped head. The objective of the game is same as golf, putting a ball into a small cup on the ground. One of the major differences of the game is the smaller size of the play ground compared to regular golf. Thus, construction of soft golf course has much smaller impact to the environment. Moreover, a Soft Golf course can be easily constructed as an attached facility to a resort or a rehabilitation institution. The game itself can be played like the game of golf but with much less risk of injury owing to soft nature of the ball and lighter swing weight of the club. On the other hand, due to the Soft Golf club's larger sweet spot area and lighter weight, the game is much easier to play. Therefore, anyone with minimal physical strength can play the game and players with variety of skill levels and physical strength can play the game together.

There have been numerous reports on the risk of injuries in golf games. Frequent injuries can occur in various joints and muscles [2]. Some of the grave dangers in golf games are the head and ocular injuries caused by hard golf balls [2]. Most of these critical injuries can be avoided in Soft Golf game.

On the other hand, physical aspects of golf have been studied by many researchers. Many analyses used simple two-dimensional link models to analyze golf swings [3, 4]. The two dimensional model can simplify the analysis but the real golf swing is three dimensional in nature and thus requires more realistic model in evaluating injury risks [5]. Nesbit et al. applied realistic computer simulation model to actual motion

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Fig. 1. Soft Golf club set with wood, iron, wedge, and putter

(a) (b)

Fig. 2. Clubs used in the comparative experiment
(a) Soft Golf iron club (b) regular iron 7 club

capture data and obtained kinematic and kinetic parameters along with work and power related parameters for golf swings [6, 7]. The current study tries to apply and extend this method toward soft golf swings to find the advantages of soft golf compared with regular golf. Moreover, this study tries to look into biomechanical aspect of Soft Golf swings and quantify the benefits of the lighter Soft Golf club. Especially, mechanical loadings to major joints such as lumbar joints have been carefully examined.

II. METHODS

Actual Soft Golf swing motions and regular golf swing motions were captured with a three-dimensional motion tracking system. The participants were nine healthy older aged adults. The average age was 66.9±6.0. The participants were all right handed and were recreational golfers who have handicaps close to 30.The subjects performed swing motion with the Soft Golf club and the iron-7 club shown in Fig. 2 in turn. The specifications of the clubs are listed in Table 1. The motions of the swings were recorded using an opto-electric motion detection system (Optotrak Certus, Northern Digital, Inc., Canada). For this purpose, the subjects wore rigid body markers that have 6 degrees of freedom (DOF) on each major moving segment of the body as shown in Fig. 3. One rigid body marker consists of three infrared-light emitting diode markers attached to a small rigid plate as shown in Fig. 3 (b) so that the coordinate locations of the three markers can represent the three-dimensional orientations as well as the location of the rigid body. The small rigid body markers were attached to the locations close to the center of major moving segments of the human body using Velcro straps as shown in Fig. 3 so that each rigid body marker, 6 degrees of freedom (DOF) marker, can give out three dimensional coordinate and three -dimensional orientations of the segments, to which it is attached. In the experiment, a total of eight rigid body markers were used. The marker attachments followed procedures of the Motion Monitor software (Innovative Sports, Inc., Chicago, USA). After 6 Degrees of Freedom (DOF) markers were attached to the eight segments of the body, the end points of the major segments were digitized into the Motion Monitor using stylus. The major segments, to which the 6 DOF markers were attached, were head, thorax, lower arms, left hand, sacrum, and lower legs as shown in Figs. 3 and 4. No markers were attached to upper arms or upper legs. The movements of those segments were approximated using coordinate locations of the 6 DOF markers and the orientation values of the 6 DOF markers attached to adjacent segments along with segment end point information relative to the 6 DOF markers. Also, the relative orientation between the left hand and the club is maintained constant during normal swing motion. Thus, the club head velocity was calculated based on

Table 1. Specifications of the regular golf and soft golf clubs used in the experiment

	Length(cm)	Weight(g)	Center of Mass
Iron 7 Club	93.5	420	0.75
Soft Golf Club	92.0	260	0.71

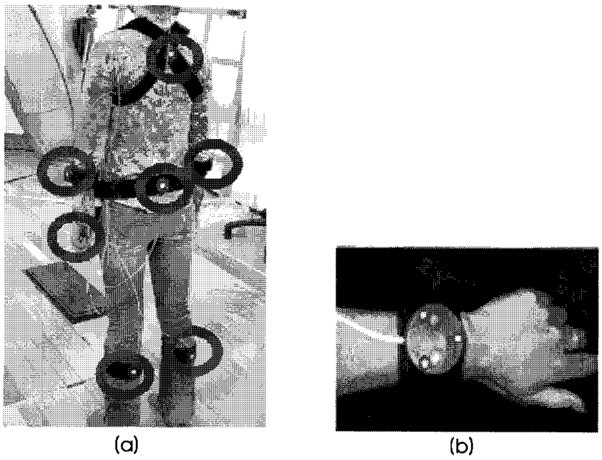

Fig. 3. Six-DOF Rigid body markers attached to major segments (a) the locations of rigid bodies (b) a rigid body with three infrared-light emitting diodes attached to left lower arm

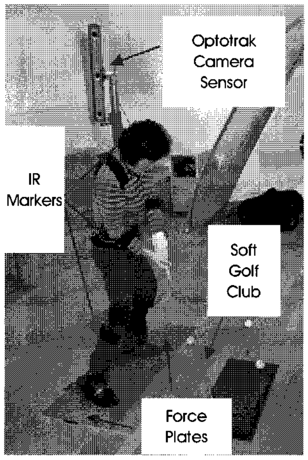

Fig. 4. A subject with wearable infrared light emitting diodes standing on two force plates.

the distance and the relative orientation between the club head and the rigid body marker attached to the left hand, which were measured in the beginning of the experiment.

In addition, two force plates with a width of 40 cm and a length of 60 cm (Bertec, Inc., USA) were used to measure ground reaction forces to both feet during swing motion. The ground reaction force measurements from the force plates and motion capture data from the motion tracking system were simultaneously collected using a specially designed Motion Monitor data collection system.

There were three Optotrak Certus sensor cameras arranged to cover all the directions of the subject when the subject was standing on the force plates and performing swing motions as shown in Fig 5. The frame rate of the motion capture was 140 frames per second. The capture rate for the analogue data, the outputs from force plates, was 1000 frames per second.

The motion data were imported to ADAMS (MSC Software, Inc., USA), multi-body dynamics solver with LifeMOD plugin (BRG Inc., USA). The type of motion data used were the joint locations and surface marker coordinates, which were exported from the Motion Monitor data acquisition system. To calculate kinematic and kinematic factors, the swing motion of the golfer was modeled using a realistic 3D simulation model. The segmental center of mass and orientation information was calculated and used to construct the simulation model. For this purpose, a realistic human model with segmental masses and inertia was constructed using LifeMOD. The model was driven by motion capture data imported to ADAMS, multi-body dynamics solver. In the simulation, the inverse problem of joint motion

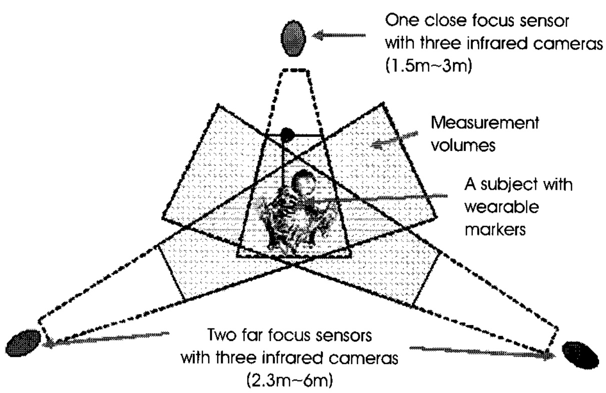

Fig. 5. Optimal placement of Optotrak camera sensors for golf motion capture

Fig. 6. A computer simulation model of a golfer with a golf club

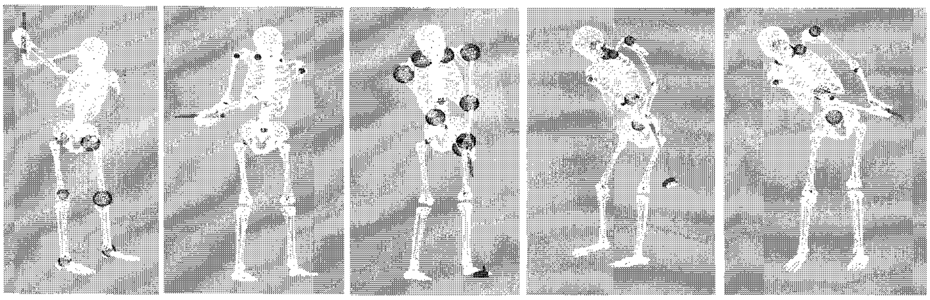

Fig. 7. Simulated magnitudes of joint moments during swing motion (The size of the sphere at the joint represents the magnitude of joint moments, time is relative to the ball impact, male subject A: Age 69, Height: 173 cm, Weight: 46 kg)

was solved first and next the forward problem of joint torque was solved.

The kinematic analysis of the Soft Golf swing was concentrated on lumbar joint mechanics where most frequent injury or pain is reported [2].Kinematics analysis was done based on motion capture data using Motion Monitor analysis package. Kinetic analysis was done by solving forward dynamics of computer simulation model based on inverse dynamics solutions based on motion capture data using implemented solution processes within LifeMOD plug-in packages and the multi-body motion analysis algorithm in ADAMS package. The main reason for using force plate measurements was checking computer simulation results.

Ⅲ. RESULTS

The list of results obtained from the motion analysis and simulation results are as follows.

1. Kinematical factors: lumbar bending angle (LBA), lumbar angular rotational velocity (ARV), lag time (timing between maximum LBA and ARV)
2. Kinetic factors: lumbar rotational torque

Figure 7 shows kinetic analysis results of the forward dynamics solution using a computer simulation model for calculation of joint torque loadings. The sizes of sphere bubbles represent higher torque loadings in the representing joint locations. As can been seen in the figure, different joints are activated in sequence at different swing stage. Among analyses of different subjects, the cases with least number of frames with missing markers were selected and plotted.

Before estimating kinetic loadings to lumbar joints, kinematic factors were observed first. Figure 8 shows lumbar lateral bending angle and lumbar rotational velocity, which are related to lower lumbar pains [9]. Morgan et. al [9] reports that extensive lateral bend along with extension at lumbar joint during follow-through can result in higher stress and chance of

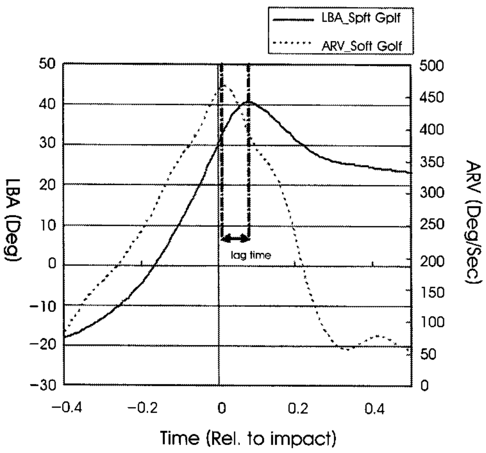

Fig. 8. The timing difference, lag time, between maximum lumbar lateral bending angle and maximum lumbar rotational angular velocity (female subject B: Age 68, Height 150cm, Weight 56kg)

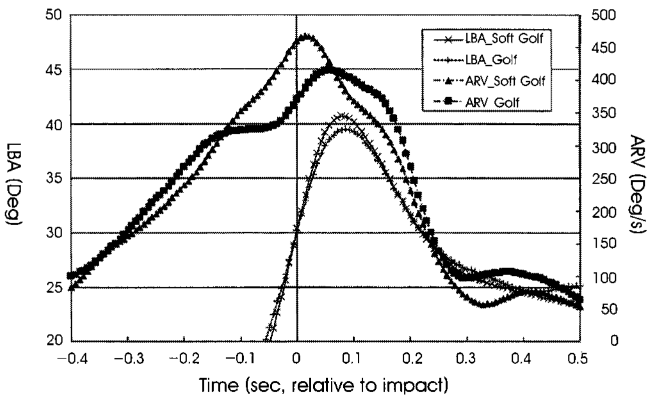

Fig. 9. Comparison of LBA and ARV for the swings using different clubs (female subject B: Age 68, Height 150cm, Weight 56kg)

Table 2. Comparison of kinematic parameters related to lower lumbar pain(LBA: lumbar lateral bending angle; ARV: lumbar angular rotation velocity lag time: timing between the occurrence of the maximum ARV and that of the maximum LBA)

	Club Head Velocity (m/sec)	LBA_{max} (deg.)	ARV_{max} (deg./sec)	Lag Time (msec)
Soft Golf	23.9±2.5	38.2±3.8	270.2±33.2	102±52
Regular Golf	19.9±2.2	41.8±4.2	241.6±65.1	78±40

injury in the lower back. The timing between the maximum values of the two factors could indicate abrupt squeezing of lumbar muscles and shorter lag time could be related to lower lumbar pain. Figure 9 shows comparison between a soft golf club swing and a regular golf club swing. Higher rotational velocity can be observed with soft golf swing. Table 2 shows calculation of LBA, ARV, and lag time. Smaller lag time can be observed with regular golf swing. Morgan et. al (1998) also explained that twisting lumbar joint at a high velocity while it is laterally bent in one direction could result in high risk of lower back pain injury due to increased shear forces on the viscoelastic tissue between facets and vertebrae. He found that players with short lag time have higher occurrences of lower back pains.

Most participants achieved higher club head speed with the Soft Golf club as can be seen in Table 2. Higher swing speed and high moment of inertia can induce higher moment requirement for stopping the motion. Therefore, lighter soft golf club would require less energy to accelerate and decelerate.

Figure 10 shows torque loadings for lumbar rotations obtained from simulation model by solving forward dynamics solutions. As can be seen in the figure, higher moment is required to accelerate and decelerate the clubs.

Ⅳ. DISCUSSIONS

The comparisons between the swings using two clubs showed:

1. Soft Golf club seems to require less torque to drive club head to reach certain speed.

2. The range of joint motion and abrupt squeezing of muscles at the lumbar joint tend to be smaller with soft golf club even when the club head speed was higher.

One popular belief about the weight about golf club is that more power would be needed to drive lighter club to reach higher speed since less weight and mass would induce smaller potential energy and smaller centrifugal force to contribute to the speed of the club head. In the study, it is projected that lighter softer club can be easier for older adults to produce more efficient form of swing to reach higher speed. This projection has been explored based on motion analysis and computational simulation model. Especially, motions at lumbar joint were carefully analyzed. As was shown in the results, the torques at lumbar joints to produce certain club head velocity was smaller with soft golf club.

The comparisons of lag time showed that the swings with soft golf club has longer lag time, which means less abrupt squeezing of lower back muscles. The obtained results for lag time were slightly longer than the results obtained by Morgan et al. (1998) for seniors with regular driver. Also, the torque values obtained from computer simulation at lumbar joint for soft golf clubs were less than the torque values obtained by Nesbit (2005) from computer simulations for swings using drivers.

There are many limitations in the developed computer

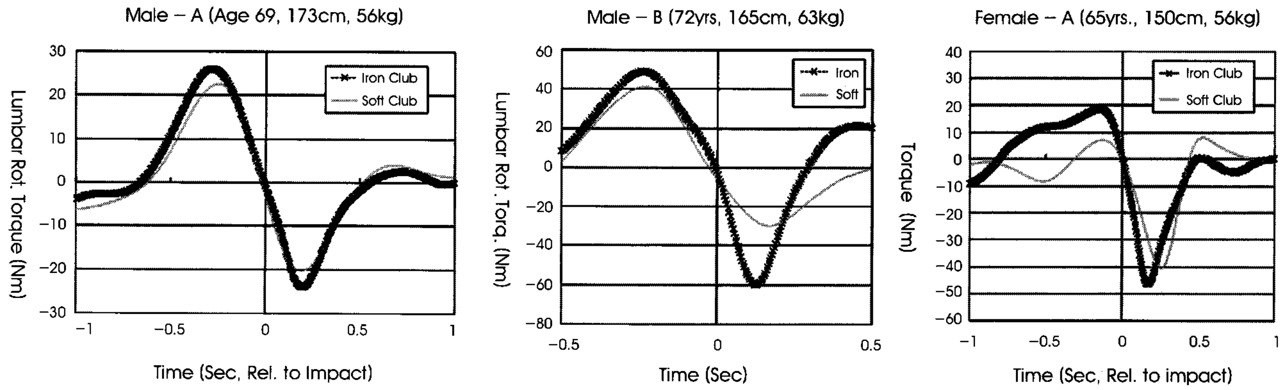

Fig. 10. Lumbar rotational torque loadings for two different clubs

simulation model due to many reasons such as simplifications of the joint limits [8], inaccurate values of segmental masses, segmental moments of inertia, and etc. Therefore, the torque values calculated from the simulation model can only be valid for relative comparison to each other since there does not exist any way to measure exact torque values generated on certain joints by attached muscles during golf swing.

Soft Golf club seems to be easier to drive and induces less torques and power from each joint and muscle to reach specific swing speed reducing risks of injuries to joints and muscles. Moreover, lighter Soft Golf club is less prone to injuries associated with poor swing mechanics and overuse.

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