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[Original article]

Analysis of trunk rotation during baseball batting with lumbar disc degeneration

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Abstract

Lower back pain (LBP) is common among baseball players, and the occurrence of lumbar intervertebral disc degeneration is high. The dynamic load on the lumbar spine due to the postures and movements characteristic of baseball is suspected of aggravating LBP caused by degeneration, but the difference in batting action between players with and without degeneration is not known. The purpose of this study was to investigate the difference in batting motion in the presence and absence of lumbar disc degeneration (LDD). The subjects were 18 male baseball players belonging to the University League Division I : seven with disc degeneration and 11 without. The motion task analyzed tee batting. The items examined were the angles of rotation of shoulder, pelvis, hip, and twisting motion ; rotation angular velocity ; time to maximum angular velocity ; and muscle activity potentials of the bilateral latissimus dorsi, erector spinae, multifidus, external oblique, internal oblique, rectus abdominis, and gluteus medius muscles ; at each stage of batting action. There were significant differences between the shoulder and pelvis in rotation angle, time to maximum angular velocity, and muscle activity in the presence and absence of LDD, and in the time to maximum angular velocity between the shoulder and pelvis. We infer that these differences are characteristic of batting motion due to LDD.

Key words : lumbar disc degeneration, trunk rotation, baseball batting

Introduction

Lower back pain in baseball is frequent along with shoulder and elbow pain[1-4)]. As it is associated with competitive sports activities, the different postures and motions in baseball may be contributing factors[5)]. There is a reported relationship between a history of lower back pain and lumbar disc degeneration : the higher the degree of lower back pain experienced, the higher the rate of disc degeneration[6)]. Baseball has a higher rate of lumbar disc degeneration than swimming, basketball, kendo, soccer, and athletics[6)]. Previous studies of baseball players' physical characteristics and lumbar disc degeneration reported a relationship between lumbar lordosis and trunk muscle cross-sectional area[7)]. Baseball players often have lower back pain in the lumbar region opposite to the dominant batting side[8)]. This suggests that specific repetitive rotation is also a risk factor. In the batting motion in particular, there is a kinetic chain from the lower limbs to the upper limbs[9,10)]. High axial rotation and high angular acceleration may indicate stressful movements of the abdomen and spine[11)]. Axial pressure and shear force are applied to the spinal column during trunk rotation, and the extension and rotation of the lumbar spine maximize the stress around the facet joints[12)].

Baseball is characterized by both lumbar rotation and hyperextension, which may make baseball athletes susceptible to developing spinal abnormalities[13)]. A difference in the lumbar flexion angle and

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maximum angular velocity in the batting motion has been reported between players with and without lower back pain, but with no difference in rotation[14]. However, the organic changes in the lumbar spine are unknown. In this study, we analyzed batting motion in players with and without lumbar disc degeneration. Considering that improper trunk rotation sequencing occurs as a combination of delayed pelvic rotation and early upper trunk rotation[15], our hypothesis was that the shoulder and hip rotation throughout the bat swing of players with disc degeneration involved a shorter kinematic sequence compared to players without disc degeneration.

Materials and methods

Participants were 18 male first-division university baseball fielders (age 20.2±1.1years ; height 1.75±0.05 m ; mass 74.3±5.7 kg ; baseball career 11.2±1.8 years). Of them, eight players bat right-handed and throw right-handed (44%), one bats left-handed and throws left-handed (6%), and nine bat left-handed and throw right-handed (50%). Participants in this study had no history of lumbar spine surgery or terminal-stage lumbar spondylolysis, and none of the athletes smoked. In addition, none of the participants had back pain at the time of motion analysis.

The study was approved by the Research Ethics Committee of the Faculty of Health and Sport Sciences, University of Tsukuba, Japan (approval number 27-118). After receiving a detailed explanation of the study, all participants signed informed consent forms.

Assessment of disc degeneration

Lumbar disc degeneration was evaluated by lumbar MR midsagittal imagery with a 0.25-T G-scan Brio (Esaote, Belgium). T2-weighted images (TR/TE = 2280/125, matrix = 256 × 252, thickness = 5.0 mm, FOV = 320 mm) were taken in the standing position (Fig. 1). Degeneration was assessed from L1/L2 to L5/S1 and was classified into 5 grades according to Pfirrmann's classification[16]. As in Hangai *et al.*[6] and Kaneoka *et al.*[17], Grade III or higher was considered sufficient indication of degenerated discs (Fig. 1). In addition, we classified participants with disc degeneration at one or more disc levels as participants with disc degeneration. The MR images were interpreted by an orthopedic surgeon with abundant clinical experience.

Motion analysis

Motion analysis was performed with the examiner and participants blinded to the MRI evaluation. Each participant wore a sleeveless shirt, tight shorts, socks, sneakers, and a cap during testing. Each participant had 47 markers attached to their body and 6 markers on the bat. The movement was tee batting with 3 swings each. The height of the tee was adjusted to the height of the participant's belt, and the position was adjusted to the center of the base. Each participant was instructed to hit toward center field with his normal batting motion. For each participant, data from the swing with the fastest bat speed were used. The test-retest reliability (intraclass correlation coefficient [ICC]) between swing trials was very high (0.93). Three-dimensional (3D) coordinate data of the batting motion (body, 47 markers ; bat, six markers) were captured using a 14-camera motion capture system (Vicon-MX, Vicon Motion Systems, Ltd., Oxford, UK) at 250 Hz (Fig. 2). Ground reaction forces of each leg were recorded on two force plates (9281A, 9287B ; Kistler Instruments AG, Winterthur, Switzerland) at 1,000 Hz. The global coordinate system treated the subject's left-right direction as the x-axis, the anterior-posterior direction as the y-axis, and the vertical direction as the z-

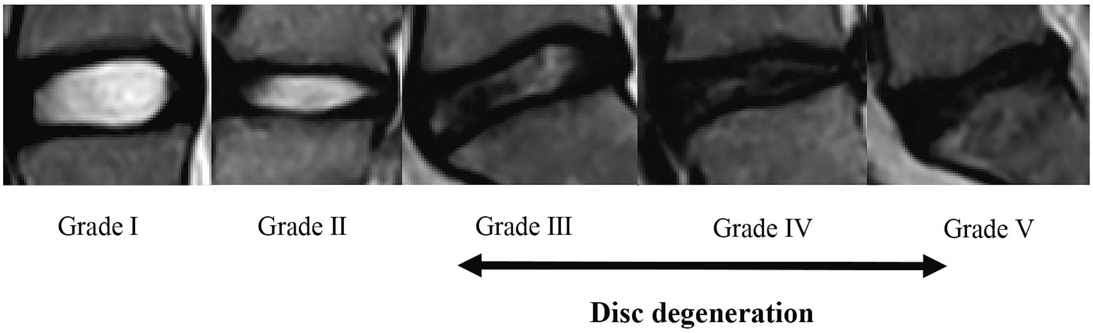
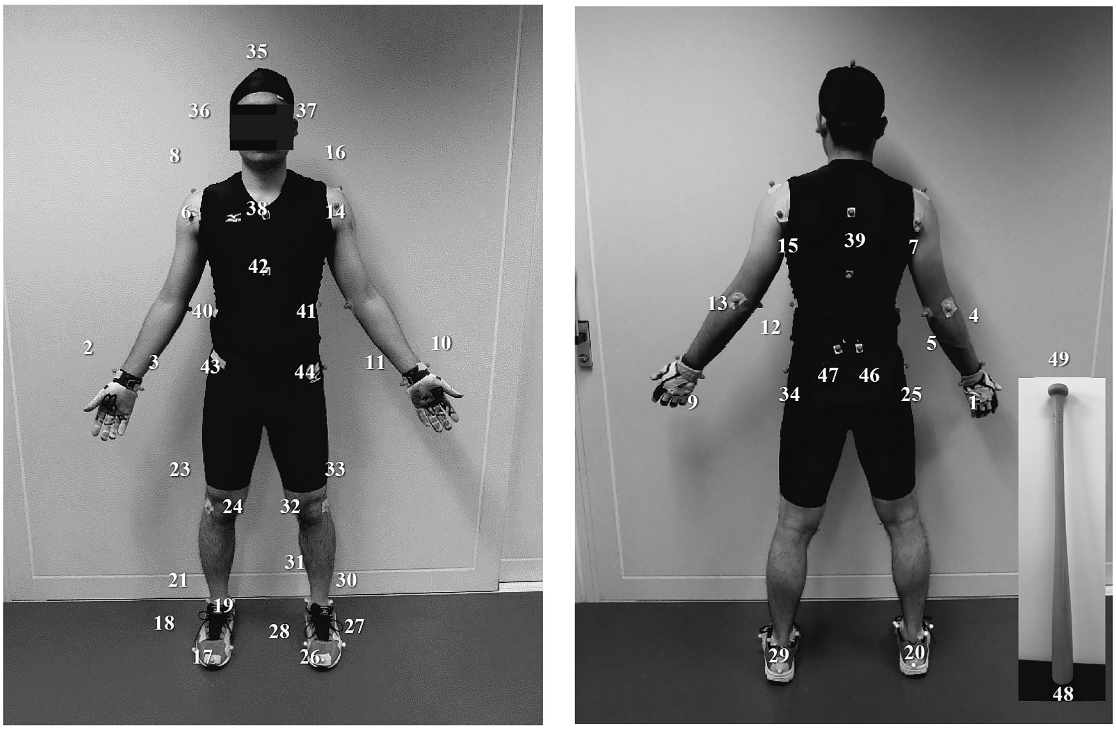


Fig. 1. Pfirrmann disc classification.
Degeneration was assessed from L1/L2 to L5/S1 and was classified into 5 grades according to Pfirrmann's classification. As in Hangai et al. and Kaneoka et al., Grade III or higher was considered to indicate disc degeneration.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1	Right 3rd metacarpal	(RHND)	17	Right toe	(RTOE)	33	Left knee medial side	(LKNM)
2	Right styloid process of ulna	(RWRL)	18	Right 1st metatarsal	(RBAL)	34	Left trochanter major	(LTRO)
3	Right styloid process of radius	(RWRM)	19	Right 5th metatarsal	(RBAM)	35	Top of head	(HEAD)
4	Right elbow lateral side	(RELL)	20	Right calcaneus	(RHEL)	36	Right ear	(REAR)
5	Right elbow medial side	(RELM)	21	Right malleolus medialis	(RAN	37	Left ear	(LEAR)
6	Right shoulder frontal side	(RSHF)	22	Right malleolus lateralis	(RKNM)	38	Suprasternals frontal side	(STEF)
7	Right shoulder back side	(RSHB)	23	Right knee medial side	(RANM)	39	Suprasternals back side	(STEB)
8	Right acromion	(RSHA)	24	Right knee lateral side	(RKNL)	40	Right rib	(RRIB)
9	Left 3rd metacarpal	(LHND)	25	Left toe	(RTRO)	41	Left rib	(LRIB)
10	Left styloid process of radius	(LWRL)	26	Right trochanter major	(LTOE)	42	Xiphoid process frontal side	(XIPF)
11	Left styloid process of ulna	(LWRM)	27	Left 5th metatarsal	(LBAL)	43	Xiphoid process back side	(XIPB)
12	Left elbow lateral side	(LELL)	28	Left 1st metatarsal	(LBAM)	44	Right anterior superior iliac spine	(RASI)
13	Left elbow medial side	(LELM)	29	Left calcaneus	(LHEL)	45	Left anterior superior iliac spine	(LASI)
14	Left shoulder frontal side	(LSHF)	30	Left malleolus lateralis	(LANL)	46	Right posterior superior iliac spine	(RPSI)
15	Left shoulder back side	(LSHB)	31	Left malleolus medialis	(LANM)	47	Left posterior superior iliac spine	(LPSI)
16	Left acromion	(LSHA)	32	Left knee lateral side	(LKNL)	48	Bat head	(BHEAD)
						49	Bat end	(BEND)

Fig. 2. Placement of the reflective markers on participants.

axis.

Data processing

We smoothed the 3D coordinate data of each subject with a second-order low-pass Butterworth digital filter to determine the optimal cut-off frequency (10.0-25.0 Hz) by the method described by Wells and Winter[18].

The joint angle used in this study indicates the angle in the horizontal plane (x-y plane). The line between the right and left acromia projected into the horizontal plane was defined as the shoulder vector. The line between the right and left greater trochanters projected into the horizontal plane was defined as the hip vector. The line between the right and left anterior iliac spines projected into the horizontal plane was defined as the pelvis vector. Angles were compared between players with and without disc degeneration. The angle between the shoulder vector and the hip vector was defined as the torsion angle of the trunk ("twist"). The angular velocities of the shoulder line, hip line, pelvic line, and twist were calculated by time-differentiation of each angle. The swing speed of the bat head was calculated by time-differentiation from the obtained coordinate values.

We analyzed several features : shoulder, hip, pelvis, and twist ; rotation angular velocity of the tee batting motion from foot release to follow-through ; rotation angle and rotation angular velocity at the points of foot release, foot contact, take-back, maximum bat speed, and follow-through (Fig. 3) ; average angular velocities from foot release to foot contact, foot contact to take-back, take-back to maximum bat speed, and maximum bat speed to follow-through ; the difference in time

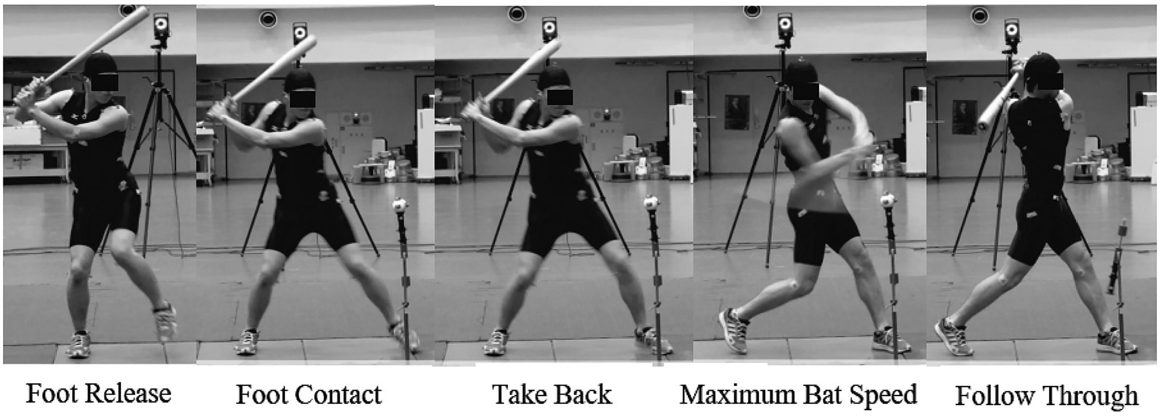


Fig. 3. Phases of baseball batting motion.
Foot release : immediately after the stepping leg is off the ground. Foot contact : when the stepping leg reaches the ground. Take-back : at the time of maximum twist angle at take-back.
Maximum bat speed : the highest speed at the top of the bat. Follow-through : time of maximum twist angle during follow-through.

from foot contact to the maximum angular velocity of the shoulder line, hip line, and pelvic line ; and the maximum angular velocities of the shoulder, hip, and pelvis.

Surface electromyogram analysis

A wireless electromyogram (EMG) sensor (Telemyo DTS, Noraxon Inc., USA) was used to record the surface electric potential from electrodes placed at the erector spinae (ES), multifidus (MF), latissimus dorsi (LD), gluteus medius (GMe), rectus abdominis (RA), external oblique (EO), and internal oblique (IO) muscles on both sides of the body. The skin was first exfoliated with a skin abrasive and alcohol-absorbent cotton to minimize artifacts.

Bipolar surface electrodes (Blue Sensor M-00-S/50, Ag/AgCl, Ambu A/S, Ballerup, Denmark) with a diameter of 34 mm were then placed on the muscle bellies and aligned 2 cm apart parallel to the muscle fibers according to the SENIAM recommendations for surface electromyography[19]. The derived myoelectric potential (MEP) was amplified by an EMG amplifier, The derived myoelectric potential (MEP) was amplified by an EMG amplifier, the signal was captured at a sampling rate of 1,000 Hz, preamplified at the source at a gain of 500 Hz, converted by 16-bit analog to digital converter. All records of myoelectrical activity were stored on a personal computer for later analysis. We measured the MEP at maximum voluntary contraction (MVC) of each muscle by adding maximum resistance using the manual muscle testing normal procedure of Daniels *et al.*[20] the subject performed maximum isometric contraction for 3 s. The root-mean-square of stable 1s measurements was used as the action potential. The myoelectric waveforms were analyzed in MR3 Myomuscle software (Noraxon Inc.). The data were bandpass-filtered at 10 to 500 Hz to remove motion artifacts and then full-wave rectified in MR3 Myomuscle.

Data were analyzed from foot release to follow-through of the forefoot. The percentage (%) MVC was calculated as the value of the muscle action potential obtained during foot release, foot contact, take-back, maximum bat speed, and follow-through divided by MEP and used as the degree of muscle activity. An external analog output module was connected to the Vicon-MX to ensure synchronization with the surface EMG and optical signals.

Statistical analysis

Statistical analyses were performed in IBM SPSS Statistics Base 25 software. Unpaired t-tests were used to evaluate the differences between the two groups in terms of shoulder, hip, pelvis, and twist angles ; angular velocities at points of foot release, foot contact, take-back, maximum bat speed, and follow-through ; in average angular velocities from foot release to foot contact, foot contact to take-back, take-back to maximum bat speed, and maximum bat speed to follow-through ; in time from foot contact to the maximum angular velocity of shoulder, hip, and pelvis ; and the time difference in the maximum angular velocity between shoulder and hip and between shoulder and pelvis. Muscle activity did not show a normal distribution, so the Mann-Whitney U-test was used. Cohen's d was calculated for the effect size of independent t-tests, with values of ≥ 0.20 and < 0.50, ≥ 0.50 and < 0.80, and ≥ 0.80 indicating a small, medium, and large effect, respectively[21]. Statistical significance was set at $P < 0.05$.

Results

Assessment of disc degeneration

Evaluation of lumbar disc degeneration showed that seven subjects (39%) had disc degeneration ; of whom three bat right-handed and throw right-handed, one bats left-handed and throws left-handed, and three bat left-handed and throw right-handed. Eleven subjects (61%) had no disc degeneration ; of whom three bat right-handed and throw right-handed, and eight bat left -handed and throw right-handed.

Batting motion analysis

Angle at each stage of action in the shoulder, hip, and twist

There were significant differences in means of the hip at foot release ($P = 0.042$, Table 1).

Angular velocity at each stage of action in the shoulder, hip, and twist

There were significant differences in the means of the shoulder at foot contact ($P = 0.048$) and in the twist in follow-through ($P = 0.028$; Table 2). Figure 4 shows an example of the rotation angle and angular velocity at the time of impact in the presence and absence of lumbar disc degeneration.

Differences in time to maximum angular velocity between the shoulder vs hip and pelvis

There were no significant differences in time to maximum angular velocity between the shoulder, hip, and pelvis (Table 3). The difference in time to maximum angular velocity between shoulder and pelvis was shorter in the group with disc degeneration ($P = 0.046$; Table 4). There was no difference between shoulder and hip.

Muscle activity analysis

At the time of maximum bat speed, muscle activity was significantly greater on the axial leg side of ES ($P = 0.044$) and the stepping leg side of GMe ($P = 0.035$) in the group with disc degeneration (Fig. 5). Follow-through was significantly greater on the stepping leg side of ES ($P = 0.035$) and the axial leg side of GMe ($P = 0.008$) in the group with disc degeneration and on the stepping leg side of LD ($P = 0.044$) in the group without disc degeneration (Fig. 6).

Table 1. Mean angle and swing speed at each stage of action in shoulder, hip, twist, and swing speed.

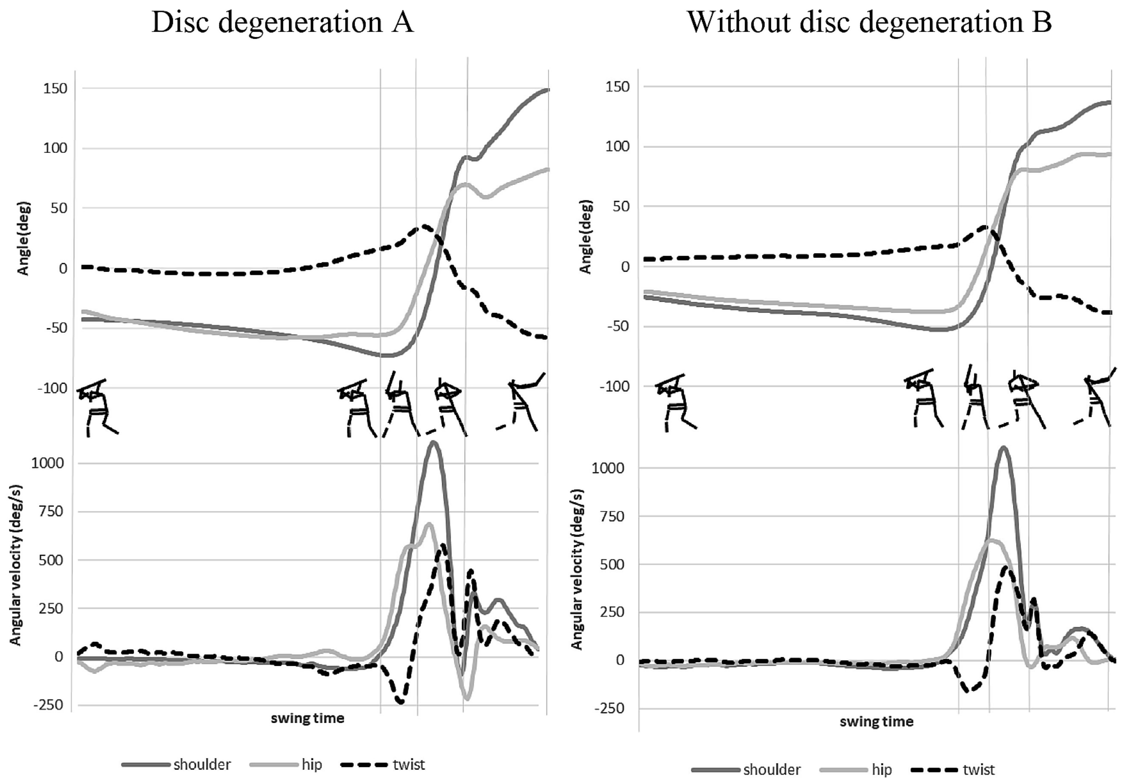
Stages measured in each joint	Disc degeneration ($n = 7$)	No disc degeneration ($n = 11$)	*$P < 0.05$	ES
Shoulder (°)				
Foot release	−31.7 ± 10.6	−22.2 ± 9.7	N.S.	0.95
Foot contact	−54.8 ± 9.8	−51.9 ± 9.1	N.S.	0.31
Take-back	−27.6 ± 13.7	−29.1 ± 12.7	N.S.	0.11
Max. bat speed	66.1 ± 10.0	66.5 ± 31.4	N.S.	0.01
Follow-through	152.0 ± 7.8	153.3 ± 13.2	N.S.	0.12
Hip (°)				
Foot release	−18.9 ± 11.2	−9.4 ± 7.2	*	1.07
Foot contact	−32.9 ± 7.7	−28.0 ± 5.1	N.S.	0.79
Take-back	5.8 ± 11.3	10.0 ± 15.6	N.S.	0.30
Max. bat speed	62.2 ± 9.5	65.4 ± 15.7	N.S.	0.23
Follow-through	88.7 ± 10.9	90.6 ± 8.4	N.S.	0.20
Shoulder − hip (“twist”) (°)				
Foot release	−12.8 ± 7.6	−12.8 ± 5.4	N.S.	0.14
Foot contact	−23.9 ± 9.6	−21.9 ± 6.1	N.S.	0.03
Take-back	−39.1 ± 10.5	−33.4 ± 4.4	N.S.	0.50
Max. bat speed	1.1 ± 16.9	4.2 ± 6.3	N.S.	0.14
Follow-through	62.7 ± 9.6	63.2 ± 12.6	N.S.	0.09
Swing speed (m/s)	35.9 ± 2.8	35.7 ± 4.3	N.S.	0.08

Values are mean ± standard deviation. N.S., not significant. Negative values are explained in Figure 2. ES, effect size.

Table 2. Mean angular velocity at each stage of action in the shoulder, hip, and twist.

Stages measured in each joint	Disc degeneration ($n = 7$)	No disc degeneration ($n = 11$)	*$P < 0.05$	ES
Shoulder (°/s)				
Foot release	−25.4 ± 27.8	−20.3 ± 11.1	N.S.	0.27
Foot contact	90.1 ± 55.1	40.9 ± 42.2	*	1.04
Take-back	592.5 ± 99.4	530.5 ± 158.2	N.S.	0.45
Max. bat speed	894.1 ± 177.1	789.3 ± 307.1	N.S.	0.39
Follow-through	8.76 ± 26.4	1.9 ± 14.5	N.S.	0.34
Hip (°/s)				
Foot release	−22.5 ± 17.8	−25.0 ± 17.2	N.S.	0.14
Foot contact	175.7 ± 107.3	155.6 ± 115.9	N.S.	0.18
Take-back	513.6 ± 94.2	471.3 ± 99.7	N.S.	0.43
Max. bat speed	334.4 ± 91.4	332.4 ± 179.7	N.S.	0.01
Follow-through	14.6 ± 28.3	3.9 ± 14.9	N.S.	0.51
Shoulder − hip (twist) (°/s)				
Foot release	−2.4 ± 19.4	4.8 ± 17.9	N.S.	0.39
Foot contact	−83.3 ± 61.4	−114.6 ± 97.8	N.S.	0.36
Take-back	77.8 ± 37.1	59.9 ± 97.1	N.S.	0.31
Max bat speed	555.9 ± 214.7	456.9 ± 228.1	N.S.	0.44
Follow-through	−6.9 ± 5.7	−1.9 ± 3.2	*	1.17

Values are mean ± standard deviation. N.S., not significant. ES, effect size.


Disc degeneration A

Without disc degeneration B

Fig. 4. An example of the rotation angle and angular velocity of the shoulder, hip, and twist during batting motion (player A with disc degeneration ; player B without disc degeneration).

Table 3. Differences in time to maximum angular velocity at the shoulder, hip and pelvis.

Difference in time to maximum angular velocity (s)	Disc degeneration ($n = 7$)	No disc degeneration ($n = 11$)	*$P < 0.05$	ES
Shoulder	0.165 ± 0.02	0.184 ± 0.03	N.S.	0.69
hip	0.126 ± 0.02	0.150 ± 0.03	N.S	0.75
pelvis	0.134 ± 0.02	0.136 ± 0.02	N.S	0.10

Values are mean ± standard deviation. N.S., not significant. Not significant. ES, effect size.

Table 4. Differences in time to maximum angular velocity between the shoulder and hip and between the shoulder and pelvis.

Difference in time to maximum angular velocity (s)	Disc degeneration ($n = 7$)	No disc degeneration ($n = 11$)	*$P < 0.05$	ES
Shoulder − hip	0.039 ± 0.02	0.034 ± 0.01	N.S.	0.27
Shoulder − pelvis	0.027 ± 0.01	0.052 ± 0.03	*	1.04

Values are mean ± standard deviation. N.S., not significant. not significant. ES, effect size.

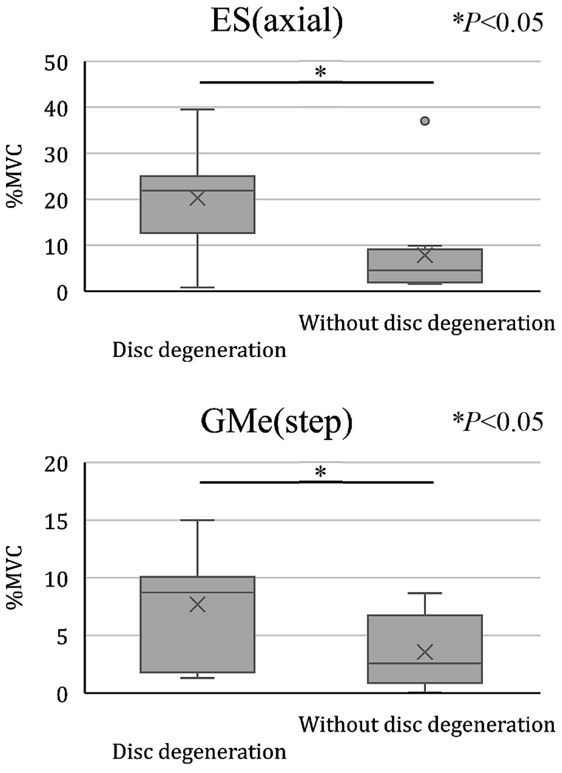


Fig. 5. % MVC of each muscle at maximum bat speed Significant differences between devices are shown with an asterisk (*) at $p \leq 0.05$

Discussion

We investigated lumbar rotation behavior and trunk muscle activity due to batting motions of university baseball players with or without lumbar disc degeneration. Our hypothesis was that the shoulder and hip rotation throughout the bat swing of players with disc degeneration had a shorter kinematic sequence compared to players without disc degeneration.

As hypothesized, we found differences between the shoulder and pelvis in the time to maximum angular velocity and in the kinematic sequence in the trunk rotation in the group with disc degeneration.

Baseball pitching and batting are achieved by activating the motor chain, which allows continuous transmission of force and movement among body segments[22-24]. Several studies have reported on sequences that affect the kinematic chain. A study investigating the effects of the order of peak pelvic and upper torso rotation velocities on joint kinetics found that delayed pelvic rotation combined with early upper torso rotation causes an improper trunk rotation sequence[15,25,26]. Here, we found no significant difference between the groups in the shoulder, hip, or pelvis in the time from foot contact to the point of maximum angular velocity. However, the difference in the time to the point of maximum angular velocity between the pelvis and the shoulder was significantly slower in the group without disc degeneration. Since there was no significant difference in the comparison of the pelvis alone, we infer that the function of the muscles and joints of the trunk, which affects the function of the distal segment, was affected by disc degeneration. In the group with disc degeneration, the rotation angle at foot release was significantly greater at the greater trochanter, and the angular velocity at foot contact was significantly greater at the acromion. In addition, the activity of the gluteus medius on the axial leg side was significantly greater. Excessive clockwise rotation (for right-handed batters) during the take-back movement of the blow produces decreased muscle

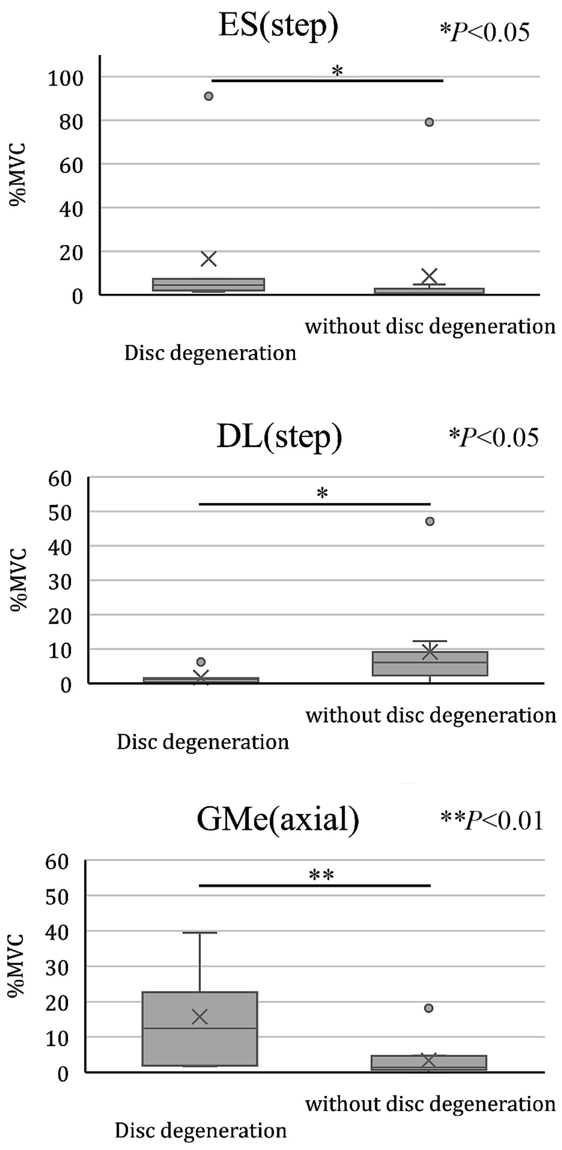


Fig. 6. % MVC of each muscle during follow-through.
Significant differences between devices are shown with an asterisk (*) at $p \leq 0.05, p \leq 0.01$

activity and confusion in the sequence[27]. In this section, the rotation angle of the greater trochanter in the negative direction is considered to have affected the angular velocity of the acromion, which is the upper limb. In addition, it is thought that the gluteus medius was active as a rotator while maintaining posture due to the activity of the axial leg side of the gluteus medius against the angular velocity of the acromion in the negative direction. The torsion angular velocity during follow-through was significantly greater in the group with disc degeneration. The muscle activity on the stepping leg side of the latissimus dorsi was significantly greater in the group without disc degeneration, and it acted as a rotation of the ipsilateral side of the trunk[28,29], which can be regarded as an appropriate kinetic chain to the upper extremities.

Owing to these differences in the kinematic sequence, it is considered that the stress on the lumbar spine is increased by increasing the difference in the twist velocity of the follow-through at the end of the swing. Since there was no significant difference in bat speed, which is an index of batting performance, it is possible that the difference in batting motion is affected by lumbar disc degeneration. Possible factors include disturbance of the kinematic sequence due to a decrease in core stability. To maintain a functional trunk, it is necessary to maintain the alignment in the neutral zone by Panjabi's motor control system[30], and trunk muscles often co-contract, stiffening the torso such that all muscles become synergists[31]. In addition, the thoracic spine and adjacent hip joint need to function as mobile joints by separating the roles of movement[32]. In the case of a decrease in core stability, biarticular muscle dysfunction causes overactivity of multi-joint muscles, which can cause traumatic injury[33]. The erector spinae muscles become overactive to compensate for decreased spinal stability[34]. Here, the gluteus medius and erector spinae muscles during trunk rotation had significantly higher muscle activity in the group with disc degeneration, suggesting overactivity due to a decrease in core stability. Increased spinal instability can lead to excessive rotation of the trunk and pelvis, which can lead to lower back pain[30,35]. In other words, these muscles compensated for the lack of stiffening of the torso due to poor lumbar stabilization.

From the above, we infer that batting biomechanics are associated with lumbar disc degeneration. Therefore, we think that performing batting motion after properly activating the lumbar spine and abdominal muscles with lumbar stabilization exercises will help prevent injuries[36]. However, since the target of this research is university players, the generalizability to other age groups is not clear. Also, the difference from actual batting is not clear because it is a trial by tee batting. It is not clear whether the load of these batting motions caused or was caused by disc degeneration because of the cross-sectional study design. In addition, it is necessary to analyze the motion analysis in actual batting and the mechanical influence on the lumbar spine by simulation using techniques such as the finite element method. We also need to examine muscle synergy by evaluating muscle coordination using non-negative matrix factorization.

Conclusion

The purpose of this study was to clarify lumbar rotation behavior and trunk muscle activity during baseball batting in the presence and absence of lumbar disc degeneration.

We found differences between the shoulder and pelvis in the time to maximum angular velocity and in the kinematic sequence in trunk rotation in the group with lumbar disc degeneration. This suggests that the kinetic chain from the lower limbs to the upper limbs is not properly performing in the group with disc degeneration during batting. We infer that the differences in rotation angle, angular velocity, and muscle activity at each stage of action between the presence and absence of lumbar disc degeneration are associated with differences in batting motion. Future research is needed to determine if disc degeneration caused the changes in batting or if batting motion causes disc degeneration.”

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this article.

Author contributions

NT, SI, SM designed and performed the study. NT carried out the analysis and interpretation of data and drafted the manuscript. All authors have critically reviewed, revised and approved the manuscript.

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