Contribution of Hip Joint Kinetics to Rotate the Pelvis during Baseball Pitching

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This study examined the effects of hip joint kinetics on pelvic rotation about the superior-inferior (SI) axis during baseball pitching from the viewpoint of energetics. Twelve right-handed males participated and all used an overarm style. Five participants were active collegiate baseball players and seven participants were former collegiate baseball players. Each participant was instructed to try their maximum effort pitch from an indoor pitching mound. Three pitches per participant that passed through the strike zone were selected for analysis. A motion capture system consisting of 13 cameras and two force platforms were used to collect data and calculate joint torques. Pelvic rotation torque, mechanical energy generation, and transfer were calculated. The hip external rotation torque transferred the mechanical energy from the thigh to the pelvis in the pivot leg, which mainly increased the mechanical energy of the pelvis about the SI axis. Regarding the stride leg, the hip adduction torque generated the mechanical energy, which mainly increased the mechanical energy of the pelvis about the SI axis. The findings highlight the importance of these torques in rotating the pelvis about the SI axis.

Keywords: pelvic rotation, hip joint torques, mechanical energy, baseball pitching

1. Introduction

Baseball pitchers are usually required to produce a high ball velocity when throwing the ball. Gray (2002) found that high ball velocity led to an error in the contact of the bat and ball. This suggests that the ability to produce high pitch velocity is critical for baseball pitchers. Therefore, it is valuable to investigate the underlying mechanisms of how baseball pitchers produce ball velocity and many researchers in the field of biomechanics have investigated this topic (Matsuo et al., 2001; Naito et al., 2011; Stodden et al., 2001).

Previous studies indicated the importance of upper torso rotation about the superior-inferior (SI) axis and showed that the angular velocity of the upper torso contributed to producing the distal endpoint velocity of the throwing arm (Hirashima et al., 2007; Urata et al., 2014). Hirashima et al. (2008) revealed that baseball players accelerated the distal endpoint during the late phase by using the angular velocity of the upper torso during the early phase. These studies indicated that generating high ball velocities can be expected by rotating the upper torso quickly about the SI axis. Therefore, Kimura et al., (2019) investigated how the upper torso rotates from the viewpoint of energetics during baseball pitching. They showed that the upper torso rotation about the SI axis was mainly caused by the pelvic rotation about the SI axis. This finding suggests that the rapid rotation of the pelvis caused by hip joint kinetics allows the rapid rotation of the upper torso, possibly resulting in high pitch velocity at the time of ball release. Therefore, it is valuable to examine the effects of hip joint kinetics on pelvic rotation during baseball pitching.

For this purpose, the pelvic rotation torque should likely be considered. The pelvic rotation torque is defined as the torque acting on the pelvis about the SI axis by the hip joint force and torque. This can clarify which hip joint force and torque rotate the pelvis about the SI axis. Several previous studies have quantified the pelvic rotation torque (Akutagawa and Kojima, 2005; Iino et al., 2014; Iino and Kojima, 2001). Moreover, a mechanical energy analysis was considered in addition to the pelvic rotation torque in this study. Previous studies examined the pelvic rotation torque (Shimada et al., 2000) and mechanical energy created by the hip joint torques in baseball pitching (Shimada et al., 2004; Hirayama et al., 2010;
Kageyama et al., 2015; Uchida et al., 2018). However, it has not been shown that how much mechanical energy of the pelvis about the SI axis is increased by the hip joint force and torque. The analysis of either the pelvic rotation torque or mechanical energy alone cannot show how much mechanical energy of the pelvis about the SI axis is increased. This can be shown by combining the two analyses. Therefore, the purpose of this study was to examine the effect of hip joint kinetics on pelvic rotation during baseball pitching from the viewpoint of energetics.

2. Methods

2.1. Participants

The participants included 12 male baseball players (age: 22.4±2.3 years, height: 1.73±0.06 m, mass, 67.6±7.4 kg, playing experience: 10.9±3.1 years), who were not injured. Five participants were active collegiate baseball players and seven participants were former collegiate baseball players, and all used an overarm style. The experimental procedure was in accordance with the Declaration of Helsinki and was approved by the ethical committee of the Graduate School of Arts and Sciences of the University of Tokyo. The study participants gave written informed consent to participate in this study and to publish these case details.

2.2. Procedure

The experiment was performed on an indoor mound designed in conformance with baseball mound criteria. Participants wore close-fitting clothing and their shoes. Forty-eight reflective markers (diameter: 20 mm) were attached to anatomical landmarks on each participant and three reflective markers were attached to the ball (Figure 1). After a warm-up, the participants were instructed to try their maximum effort pitch from the indoor pitching mound to a strike zone (height: 0.64 m, width: 0.38 m) positioned at a distance of 5 m away. They were allowed enough rest (60 s) between pitches to avoid the effects of fatigue. Three pitches per participant that passed through the strike zone were selected for analysis.

2.3. Data collection

A motion capture system consisting of 13 cameras (Motion Analysis Corporation, Santa Rosa, CA, USA) recorded the three-dimensional coordinates of the position of the reflective markers (sampling rate: 200 Hz). Ground reaction force (GRF) was recorded using two force platforms (Force Plate 9281E, Kistler, Switzerland, 0.6 m×0.4 m), at a sampling rate of 2000 Hz, and was synchronized with the motion data. The X, Y, and Z axes of the global coordinate system (GCS) were defined rightward-leftward, forward-backward and upward-downward directions, respectively.

2.4. Phases of the pitching motion

The pitching motion was divided into three phases as previously defined (Fleisig et al., 1996) (Figure 2). The stride phase was from the maximal knee height (MKH) of the stride leg to the stride foot contact (SFC). The arm cocking phase was from the SFC to the maximal external shoulder rotation (MER) of the throwing arm. The arm acceleration phase was from the MER to ball release (BR). The SFC was defined as the instant when the vertical GRF exceeded 10 N (Oyama et al., 2013). The BR was defined as the instant when the distance between any of the markers on the ball and the marker on the throwing hand increased by more than 2 cm (Nissen et al., 2007). The time from MKH to BR was divided into 100 parts and normalized (MKH: 0%, BR: 100%). A cubic spline function was used to normalize the data.

2.5. Data analysis

The data analysis was performed using MATLAB 2015a (MathWorks Inc., Natick, MA, USA). The position coordinates of the markers were smoothed by applying a bidirectional fourth-order Butterworth low-
pass filter. A residual analysis (Winter, 2009) was performed to identify the optimal cut-off frequency for each of the three-dimensional positions of each marker in each trial. A range of cut-offs between 7 and 15 Hz was used for the dataset. The GRF data were smoothed using a Butterworth low-pass digital filter with a cut-off frequency of 15 Hz to prevent artifacts from appearing in the joint torque (Bisseling and Hof, 2006; Kristianslund et al., 2012).

The position coordinates of the middle point of the ball were calculated using the position coordinates of the left and right side of the ball. Then, the ball velocity was calculated by differentiating the middle point of the ball. The error of the marker position coordinates measured by the motion capture system was approximately 1 mm. When measuring the marker position coordinates at 200 Hz, the effect of the error of 1 mm on the ball velocity was 0.2 m/s. Therefore, it was considered that the error had little effect on the ball velocity. However, the ball velocity depended on the location of the marker on the ball using this calculation method.

The whole body was modelled as 16 rigid link segments (hands, forearms, upper arms, feet, shanks, thighs, head-neck, upper torso, abdomen, and pelvis) linked by 15 joints. The inertial parameters for each segment were estimated according to the definition of these previous studies (Dumas et al., 2007a; Dumas et al., 2007b; Dumas et al., 2015). Knee and ankle joint centers were defined as the midpoints between the medial and lateral markers of the joints. The hip joint was estimated using the method developed by Harrington et al., (2007). A right-handed local coordinate system was defined for each segment in each frame according to previous studies (Dumas et al., 2007a; Dumas et al., 2007b; Dumas et al., 2015).

The joint angular velocity was calculated by subtracting the angular velocity of proximal segment from that of the distal segment in the GCS. Then, each joint angular velocity was transformed into the right-handed orthogonal local coordinate system at each joint. The joint force and torque of the ankle, knee, and hip joints were calculated using inverse dynamics in the GCS. Then, each joint torque was transformed into the right-handed orthogonal local coordinate system at each joint and normalized by the body mass. The hip joint force and the hip joint center velocity were transformed into the pelvis coordinate system (x_pel: lateral-medial axis; y_pel: anterior-posterior axis; z_pel: superior-inferior axis). The x_pel was the vector from the left anterior superior iliac spine (ASIS) to the right ASIS. The z_pel was the cross product of the vector from the center of the left and right posterior superior iliac spine (PSIS) to the center of the left and right ASIS and the x_pel. The y_pel was the cross product of the z_pel and x_pel (Figure 3a). The hip joint force in the pelvis coordinated system was normalized by the body mass.

The pelvic rotation torque was calculated by projecting the hip joint force and torque onto the SI axis of the pelvis. For example, the equation for the component of the hip abduction/adduction torque for the pelvic rotation torque (τpel_ab/ad) is as follows:

\[
τ_{\text{pel,ab/ad}} = \mathbf{e}_{\text{pel,z}} \cdot \begin{bmatrix} R_{\text{hip}} \end{bmatrix} \cdot \begin{bmatrix} \tau_{\text{hip,ab/ad}} \end{bmatrix}
\]

where \( \mathbf{e}_{\text{pel,z}} \) is the unit vector along the SI axis of the pelvis, \( R_{\text{hip}} \) is the transformation matrix from the local coordinate system of the hip joint to the GCS, and \( \tau_{\text{hip,ab/ad}} \) is the hip abduction/adduction torque vector. The contribution of the hip joint torque to the pelvic...
rotation torque depends on the hip joint angles. For example, the right hip adduction torque contributes to the pelvic rotation torque when the right hip joint is flexed. However, this torque does not make a contribution when the right hip joint is in the neutral position. The equation for the component of the hip joint force for the pelvic rotation torque ($\tau_{pelJF}$) is as follows:

$$\tau_{pelJF} = e_{pel z} \cdot \left( r_{cg\rightarrow hip} \times \begin{pmatrix} F_x \\ F_y \\ F_z \end{pmatrix} \right)$$  \hspace{1cm} (2)

where $r_{cg\rightarrow hip}$ is the position vector from the center of mass of the pelvis to the hip joint center and $F$ is the hip joint force vector in the GCS.

The segment torque power was calculated as the dot product of the joint torque and segment angular velocity. The joint torque power was calculated as the dot product of the joint torque and joint angular velocity. The hip joint force power was calculated as the dot product of the hip joint force and hip joint velocity in the pelvis coordinate system. The powers of the pelvis about the SI axis were calculated as the dot product of the pelvic rotation torque and the angular velocity of the pelvis about the SI axis ($\omega_{pel z}$). The equation for the components of the powers of the pelvis about the SI axis exerted by the hip abduction/adduction torque ($P_{pel ab/ad}$) is as follows:

$$P_{pel ab/ad} = \tau_{pel ab/ad} \cdot \omega_{pel z}$$  \hspace{1cm} (3)

The work of the pelvis was calculated by integrating the powers of the pelvis. There were two intervals of integration. One was the increase interval between $t_p$ (the time when the peak value of the angular velocity of the pelvis occurs) and $t_s$ (the last time when the angular acceleration changed from the negative to positive between MKH and $t_p$) (Figure 3b). The other was the decrease interval between $t_p$ to BR (Figure 3b).

2.6. Statistical analysis

The means and standard deviations (SD) were calculated for all variables by using the data of all participants. The data for each participant were the means of three successful trials. Pearson’s correlation coefficient test was conducted to investigate the relationship between the work of the pelvis about the SI axis by the hip joint force and torque and the ball velocity. Statistical significance was set at $p<0.05$. All statistical analyses were performed using the statistical package R (version 3.3.1 for Windows).

3. Results

The mean ball velocity was $28.8 \pm 3.0$ m/s. The average of the angular velocity of the pelvis about the SI axis is shown in Figure 3b. Positive values indicated that the pelvis rotated in the throwing direction. The angular velocity increased before the SFC and the peak value of the angular velocity occurred during the arm cocking phase. The angular velocity decreased after the peak value of the angular velocity.

The positive values of the joint torque power indi-
icated that joint torque generates mechanical energy. For example, the angular velocity and joint torque about the abduction/adduction axis of the pivot leg showed negative values during the latter half of the increase interval (Figure 4a, 4b). Therefore, the values of joint torque power showed positive values during this interval (Figure 4c). This indicated that the adduction torque of the pivot leg generated the mechanical energy. The angular velocity and joint torque about the abduction/adduction axis of the pivot leg showed negative values during the latter half of the increase interval (Figure 4d, 4e). Therefore, the values of joint torque power showed positive values during this phase (Figure 4f). This indicated that the adduction torque of the stride leg also generated mechanical energy.

The hip joint force of the stride leg in the anterior-posterior direction showed negative values during the decrease interval (Figure 5e). This indicated that the hip joint force of the stride leg acted toward the posterior direction on the pelvis. The hip joint velocity of the stride leg in the anterior-posterior direction also showed negative value during the latter half of the decrease interval (Figure 5f). Therefore, hip joint force power of the stride leg in the anterior-posterior direction showed positive value during the latter half of the decrease interval (Figure 5f).

When one segment torque power was positive and the other segment torque power was negative, the joint torque transferred mechanical energy. As shown in Figure 6c, the thigh segment torque power created by the hip external rotation torque of the pivot leg was negative during the increase interval. The pelvis segment torque power created by the hip external rotation torque of the pivot leg was positive during this interval (Figure 6c). This indicated that the hip exter-

![Figure 4](image_url) **Figure 4** The average of the hip joint angular velocity, hip joint torque, and hip joint torque power. (a) Hip joint angular velocity, (b) hip joint torque, and (c) hip joint torque power of the pivot leg. (d) Hip joint angular velocity, (e) hip joint torque, and (f) hip joint torque power of the stride leg. The left and shaded area represents the increase and decrease interval, respectively.
Figure 5 The average of the hip joint velocity, hip joint force, and hip joint force power in the right-handed orthogonal pelvis coordinate system. (a) Hip joint velocity, (b) hip joint force, and (c) hip joint force power of the pivot leg. (d) Hip joint velocity, (e) hip joint force, and (f) hip joint force power of the stride leg. The left and shaded area represents the increase and decrease interval, respectively.

Figure 6 The average of the thigh segment torque power, pelvis segment torque power, and joint torque power. The power by the hip joint torque of (a) flexion/extension axis, (b) abduction/adduction axis, and (c) external/internal rotation axis of the pivot leg. The power by the hip joint torque of (d) flexion/extension axis, (e) abduction/adduction axis, and (f) external/internal rotation axis of the stride leg. The left and shaded area represents the increase and decrease interval, respectively.
nal rotation torque of the pivot leg transferred the mechanical energy from the thigh to the pelvis during this interval.

Positive values of the powers of the pelvis indicated that the pelvic rotation torque increased the mechanical energy of the pelvis about the SI axis (Figure 7b, 7d). The component of the hip external/external rotation torque of the pivot leg was positive during the increase interval (Figure 7b). The hip external rotation torque of the pivot leg acted during this interval (Figure 4b). Therefore, the hip external rotation torque of the pivot leg increased the mechanical energy of the pelvis about the SI axis and had large positive work during this interval (Figure 8a). The component of the hip abduction/adduction torque of the pivot leg was positive during the increase interval (Figure 7b). The hip abduction torque of the pivot leg acted during this interval (Figure 4b). Therefore, the hip abduction torque of the pivot leg increased the mechanical energy of the pelvis about the SI axis during this interval and was significantly correlated with ball velocity (Figure 8a). The component of the hip abduction/adduction torque of the stride leg was positive during the increase interval (Figure 7d). The hip adduction torque of the stride leg acted during this interval (Figure 4e). Therefore, the hip adduction torque of the stride leg increased the mechanical energy of the pelvis about the SI axis and had large positive work during this interval (Figure 8b).

Regarding the decrease interval, the component of the hip abduction/adduction torque of the stride leg was negative (Figure 7d). The hip abduction torque of the stride leg acted when the component was negative during this interval (Figure 4e). Therefore, the hip abduction torque of the stride leg decreased the mechanical energy of the pelvis about the SI axis and had large negative work (Figure 8d). The component of the hip joint force of the stride leg was positive during the decrease interval (Figure 7d). The hip joint force

![Figure 7](image-url)  
**Figure 7** The average of the pelvic rotation torque and power of the pelvis about the SI axis. (a) Pelvic rotation torque and (b) power of the pelvis by the hip joint force and torque of the pivot leg. (c) Pelvic rotation torque and (b) power of the pelvis by the hip joint force and torque of the stride leg. The left and shaded area represents the increase and decrease interval, respectively.
force of the stride leg acted in the posterior direction on the pelvis during this interval (Figure 5e). Therefore, the hip joint force of the stride leg exerted to the posterior direction on the pelvis decreased the mechanical energy of the pelvis about the SI axis and had large positive work (Figure 8d).

4. Discussion

4.1. Validity of the results in this study

The pattern and amplitude of the angular velocity of the pelvis about the SI axis (Figure 3b) were comparable to those reported in the previous study (Escamilla et al., 1998). Furthermore, the patterns of the joint angular velocity, torque, and torque power were similar to those reported in a previous study (Shimada et al., 2000). These consistencies support the validity of the results of this study.

The participants were instructed to try their maximum effort pitch from the indoor pitching mound to a strike zone positioned at a distance of 5 m away. However, during actual pitching, the baseball pitcher throws from a distance of 18.44 m. This means that the participants threw during a situation that was different from that of actual pitching. However, a previous study showed that the differences in mound height and throwing distance had little effects on kinematics and kinetic variables (Fleisig et al., 2018). The difference in the throwing distance between 5 m and 18.44 m may have a large effect on kinematic and kinetic variables of the finger, but it may have little effect on kinematic and kinetic variables of the lower limbs. Therefore, it was considered that such a difference in the throwing distance had little effects on the results of this study.

4.2. Mechanical energy generation and transfer of hip joint torques

To examine which hip joint torque generated and transferred the mechanical energy, joint and segment torque power created by the hip joint torque of both legs were quantified. The hip extension and adduction
torques generated the mechanical energy during the first and latter half of the increase interval, respective-
ly (Figure 4b and 4c). On the other hand, the hip ex-
ternal rotation torque of the pivot leg generated little mechanical energy (Figure 4b and 4c). Regarding the
stride leg, the hip adduction torque generated the me-
chanical energy during the latter half of the increase interval (Figure 4e and 4f). This was similar to the
results of a previous study that showed that hip exten-
sion and adduction torque of the pivot leg and hip ad-
duction torque of the stride leg generated mechanical
energy (Shimada et al., 2000).

One of the main objectives of the pitching motion is to produce the velocity as the ball is released from the
pitcher’s hand. This is achieved by generating me-
chanical energy in the kinetic chain. At the initiation
of the pitching motion, mechanical energy is generat-
ed in the legs. The hip flexion/extension and abduc-
tion/adduction muscles are larger in volume and more
powerful than the hip external/internal rotation mus-
cle. Therefore, the torques of the flexion/extension and
abduction/adduction axes were utilized to generate the
mechanical energy, not the torques of the external/ in-
ternal rotation axis. Then, why did these torques
generate mechanical energy? The forward motion of
the whole body is initiated by the hip abduction
movement of the pivot leg. The hip abduction torque
of the pivot leg acted during before the increase phase
(Figure 4b). This indicated that the hip abduction
torque of the pivot leg moved the whole body for-
ward. However, this torque generated little mechanical
energy (Figure 4c), which suggested that little me-
chanical energy was generated yet in this phase. The
whole body rotates after it moves forward. The hip
extension and adduction torque of the pivot leg and
the hip adduction torque of the stride generated the
mechanical energy during the increase phase (Figure
4b, 4c, 4e, and 4f). This indicated that these torques
rotated the whole body, which suggested that most of
the mechanical energy for the acceleration of the ball
is generated in this phase.

The hip external rotation torque of the pivot leg tran-
ferred the mechanical energy from the thigh to the
pelvis rather than generating the mechanical ener-
gy (Figure 4b and 6e). The results indicated that the
increase in the angular velocity of the thigh in the
pivot leg was expected to lead to an increase of the
angular velocity of the pelvis. Previous studies exam-
ined which hip joint torque generated the mechanical
energy and noted the importance of the torques of
the flexion/extension and abduction/adduction axes
(Hirayama et al., 2010; Kageyama et al., 2015; Shimada et al., 2000). Few studies of the hip joint
motion about the superior-inferior axis have been
performed; however, some studies reported the impor-
tance of the movement of the hip internal rotation
(Fleisig et al., 1996; Weber et al., 2014). Weber et al.
(2014) suggests that transferring mechanical energy to
the throwing arm can be challenging if the thrower
lacks the hip internal rotation of the pivot leg during
the stride phase. Furthermore, the lack of the hip in-
ternal rotation of the pivot leg can lead to loading on
the throwing arm to maintain ball velocity. Based on
the findings of this study and these previous studies,
the internal rotation velocity of the thigh may be im-
portant for producing the ball velocity.

4.3. Pelvic rotation torque from the viewpoint of energetics

The hip external rotation torque of the pivot leg in-
creased the mechanical energy of the pelvis about the
SI axis and had large positive work during the in-
crease interval (Figure 7b and 8a). The hip adduction
torque of the stride leg increased the mechanical en-
ergy of the pelvis about the SI axis and had large po-
itive work during the increase interval (Figure 7d and
8b). It can be considered that this was because the hip
joint of the stride leg was flexed and the hip adduction
torque acted. Hip adduction torque does not mechani-
cally act to rotate the pelvis about the SI axis if the
hip joint is in the neutral position, not flexed. To
summarize these results and the results of mechanical
energy analysis, the hip external rotation torque of the
pivot leg transferred the mechanical energy from
the thigh to the pelvis, which mainly increased the me-
chanical energy of the pelvis about the SI axis. Regard-
ing the stride leg, the hip adduction torque
generated the mechanical energy, which mainly in-
creased the mechanical energy of the pelvis about the
SI axis.

The hip extension torque of the pivot leg generated
the mechanical energy and it led to the increase of the
mechanical energy of the pelvis during the first half of
the increase phase (Figure 4b and 6a). The hip ad-
duction torque of the pivot leg also generated the me-
chanical energy and it led to the increase of the me-
chanical energy of the pelvis during the latter half of
the increase phase (Figure 4b and 6b). However, the
positive works of these torques on the pelvis about the
SI axis were lower than that of the hip external rotation torque of the pivot leg (Figure 8a). This indicated that the hip extension and adduction torques of the pivot leg acted to rotate the pelvis about the lateral-medial or anterior-posterior axes. The pelvic rotation torque about the SI axis was analyzed because the point of this study was to clarify how much the hip joint force and torque contribute to increasing the angular velocity of the pelvis about the SI axis. However, analyzing the pelvic rotation torque about the lateral-medial and anterior-posterior axes may also be important because it could clarify the functions of the hip joints during baseball pitching.

The positive work of the hip joint force in the stride leg was not particularly large compared to that of the hip joint torques in the stride leg during the increase interval (Figure 8b). However, the positive work of the hip joint force in the stride leg was considerably higher than that of the hip joint torques in the stride leg during the decrease interval (Figure 8d). This indicated that the joint force of the stride leg does not contribute much to the increase of the angular velocity of the pelvis about the SI axis when the angular velocity is increasing. The hip abduction torque of the stride leg decreased the mechanical energy of the pelvis about the SI axis and had large negative work during the decrease interval (Figure 8d). Consequently, the angular velocity of the pelvis about the SI axis decreased (Figure 3b).

The works of the hip joint force and torques on the pelvis about the SI axis was not correlated with the ball velocity, except for the positive work of the hip adduction torque of the pivot leg during the increase interval (Figure 8a). A previous study reported an analysis similar to the one performed for this study and showed that there was little correlation between the work of the hip joint forces and torques of the lower limbs and ball velocity at the time of ball release (Shimada et al., 2000). The joint forces and torques of the upper limbs can directly accelerate the ball compared to that of lower limbs. The work of joint forces of upper limbs was more correlated with ball velocity than the works of the joint forces and torques of the lower limbs (Shimada et al., 2004). Therefore, it is considered that the hip joints increase the mechanical energy of the pelvis about the SI axis by generating and transferring the mechanical energy, thus indirectly contributing to the acceleration of the ball.

The examination of the effects of hip joint kinetics on pelvic rotation about the SI axis from the viewpoint of energetics made it possible to explain the mechanical energy flow from the pelvis to the throwing arm. This study showed that the hip external rotation torque transferred the mechanical energy from the thigh to the pelvis of the pivot leg, which mainly increased the mechanical energy of the pelvis about the SI axis. It also showed that the hip adduction torque of the stride leg generated the mechanical energy, which mainly increased the mechanical energy of the pelvis about the SI axis. Kimura et al., (2019) showed that the torsional torques transferred the mechanical energy from the pelvis to the upper torso. Then, the centrifugal force in the throwing arm transferred the mechanical energy from the upper torso to the throwing hand (Naito et al., 2011). One previous study examined mechanical energy flow between whole body segments during baseball pitching (Shimada et al., 2004). The results of this study can be regarded as a more specific explanation about the energy flow from the thigh to the pelvis.

This study showed the effect of hip joint kinetics on pelvic rotation about the SI axis at maximum effort pitch. Given producing high pitch velocity, it would be valuable to obtain information about the submaximal effort pitch as well as the maximum effort pitch. This indicates which variable change or does not change as the ball velocity grows up. The variables that change with increasing ball velocity may contain suggestive information about producing high pitch velocity. Therefore, the future research topic is to show the effect of hip joint kinetics on pelvic rotation at the submaximal effort pitch.

4.4. Limitations

This study had some limitations. The ball velocity of baseball players in this study (28.8±3.0 m/s) seemed to be less than the general ball velocity of skilled baseball pitchers. For example, Fleisig et al., (1999) reported that the ball velocity of collegiate and professional pitchers ranged from 35 to 37 m/s. Therefore, the findings of this study may not be generalizable to professional pitchers. Similarly, it is not clear whether the findings can be generalized to high school or adolescent baseball players. To cope with these problems, it is necessary to collect data of the participants in a wide range of performance levels and ages in future studies. Another limitation was related to the calculation of mechanical energy. The method used to
calculate mechanical energy in this study cannot evaluate the effects of two-joint muscles because it assumed that the joint torque was produced by single-joint muscles (Robertson and Winter, 1980; Zatsiorsky, 2002). Therefore, the effects of two-joint muscles cannot be discussed in this study.

5. Conclusion

The hip external rotation torque transferred the mechanical energy from the thigh to the pelvis in the pivot leg, which mainly increased the mechanical energy of the pelvis about the SI axis. Furthermore, the hip adduction torque of the stride leg generated the mechanical energy, which mainly increased the mechanical energy of the pelvis about the SI axis. The findings of this study highlight the importance of these torques in rotating the pelvis.

Disclosure statement

There are no conflicts of interest to disclose for the authors.

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