
Lower Extremity Injuries of Volleyball Players During Moving Spike Landing

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Abstract: Volleyball games worldwide have developed into aggressive volleyball games involving various types of attacking techniques. Among the various attacking techniques, the moving spike is most likely to cause body imbalance. When volleyball players perform a moving spike, to acquire more time and space when hitting the ball, they typically change their attack angle, timing, and position continually. Previous studies on run-up and landing have typically focused on vertical or forward landing. However, in actual sports scenarios, the directions of an attack landing may vary according to situations. To clarify the various sports injuries of volleyball players may sustain from landing after performing a moving spike, 10 male open level volleyball players were recruited from universities to perform 72-cm moving spike landing maneuvers. In the experiment, 11 digital motion cameras were used for 3D image capture, reflective markers were applied to track the locations of the body joints, and two AMTI 3D force plates were used to collect ground reaction force generated by the landing. The results revealed that the participant with the highest risk of sustaining a cruciate ligament tear was 172-cm tall and weighed 63 kg. The negative tibial shear force and horizontal reaction force generated from performing a moving spike were deduced to cause collateral ligament injuries to the participants who had played volleyball for 9–10 yrs. Therefore, we deduced that when volleyball players continually perform moving spike landing maneuvers without appropriate cushioning maneuvers and gear protection during training or competition, their collateral ligaments may develop chronic tendinitis.

Keywords: Volleyball, Moving Spike, Landing, Lower Extremity Injuries

1. Introduction

Contact sports (e.g., soccer, judo, basketball) and noncontact sports (e.g., volleyball, badminton) involve similar levels of danger. The actions involved in noncontact sports, such as jumping, landing on one foot, stopping and changing directions, and bumping into other players, may also cause damage to knee and ankle joints. For example, volleyball requires the continual sequence of approach, take-off, spike, and landing, which can cause an excessive force of impact on the legs and subsequent cruciate ligament injuries [1]. Previous studies have reported that jumping must be followed by cushioning of the forces during landing. When a sport is played on a surface with a low shock-absorbing ability, the flexion angles of the lower extremity joints and the angle of displacement in the knee and hip joints must be increased to effectively reduce the ground reaction force after jump-landing [2] [3]. When a player performs a moving spike

in volleyball, he or she must shift their position, timing, and angle to interrupt the opponents' blocking rhythm, timing, and space. When landing, players might lose their balance and land on one foot or exert more displacement and reaction force on the lower extremity joints, resulting in a sports injury. Reports have indicated that one-foot landing after performing a spike exposes the lower extremities to ground reaction forces and body weight, thereby increasing the risk of injury to the knee joints [4].

In actual volleyball gameplay scenarios, landings during a moving spike may occur in multiple directions rather than just one direction. Studies have shown that lower extremity injuries, including anterior cruciate ligament (ACL) rupture or ankle sprains, are often caused by sidestep maneuvers such as side-step (horizontal) or cross-step (diagonal) cutting [5~8]. When an attacking technique involves more side-step or close-step maneuvers, the difficulty in performing the technique will increase. Overcoming this difficulty in

performing attacks is crucial. Studies worldwide have investigated the forward landing of the human body at various heights as well as the influence of other factors. Devita et al. [9] compared three jump-landing patterns performed by 11 female volleyball players. Although all the three patterns involved jumping with both feet, the three patterns were specifically, landing on both feet, landing on the preferred foot, and landing on the nonpreferred foot. The electromyographic performance and ground reaction force generated during the jump-landing sequences (actions) were analyzed. In [10], the biomechanics of one-foot drop landing at two heights (30 and 60 cm) were investigated, revealing that the landing impact on the human body, shear force exerted on the lower extremity joints, as well as the axial force and Achilles tendon force increased following the increase in drop landing height. These results indicate that the type of landing method can affect sports performance and injury risk.

Studies on ankle angles have reported that greater degrees of ankle and plantar flexion at the moment of landing enable the human body to absorb the impact force from the ground and reduce the peak vertical ground reaction force [11]. Regarding knee angles, studies on the risk of ACL injuries have indicated that the knee joints can exhibit large flexion angles when the human body lands. Compared with soft landing, stiff landing generates higher ground reaction force and resultant actions between the patellar ligament and tibia; consequently, knee bending is inhibited and the forward motion of the tibia relative to the femur is increased, potentially causing a cruciate ligament rupture [12] [13]. Studies on hip angles have maintained that when the human body lands, an increased hip flexion mitigate the load from the landing impact, thereby reducing the risk of injury [2]. Hip angle affects the impact force generated during landing sequences. Decreasing the hip flexion angle causes a greater eccentric contraction of the quadriceps and an increase in knee extension torque, thereby increasing the ground reaction force and risk of ACL injuries [14]. Overall, 44% of the energy during a landing sequence is absorbed by the ankle joints, 34% is absorbed by the knee joints, and 22% is absorbed by the hip joints [6] [15].

Few studies have investigated the biomechanics of the landing sequence involved in moving spike. To prevent volleyball players from unintentionally injuring their lower extremity joints and muscle systems when performing moving spike in long-term training, investigating lower extremity joint injuries caused by the landing in such attacks is imperative. In the present study, inverse dynamic parameters were applied to analyze the effects of body height, weight, and years of experience as a player (hereafter, playing experience) on the sagittal and frontal facet joints in their lower extremities of Taiwan's University Volleyball League players during the landing sequence of their moving spike. The parameters were examined through one-way analysis of variance (ANOVA) and compared using the least significant differences test to clarify the differences among the players during their moving spike. For volleyball coaches, players, and fans at all levels, the results clarify the structural changes

in the human body during the landing sequences of moving spike, and improves the integrity of studies on landing biomechanics. In addition, the present study provides cushioning strategies for landing and a reference for coaches and players during competition and training and for protective equipment designers.

2. Methodology

2.1. Participants

A total of 10 men's University Volleyball League players were selected to perform 72-cm slide attack landing actions. Before the formal experiment, the participants were informed about the experimental procedures and requested to complete a participant consent form and demographic data table. Subsequently, the participants received training on how to perform the actions. The participants were instructed on the methods for performing the position 2 and position 3 run and jump-landing sequences and to rotate and hit the ball in midair. Figure 1 shows the basic volleyball positions, Table 1 lists the demographic data of the participants, Figure 2 is a chart defining the lower extremity joint angles.

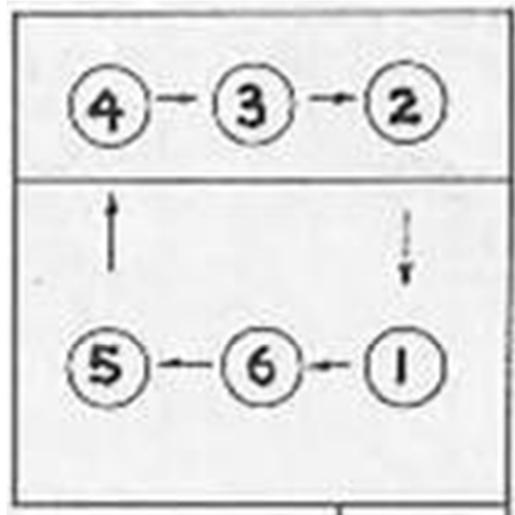


Figure 1. Volleyball positions.

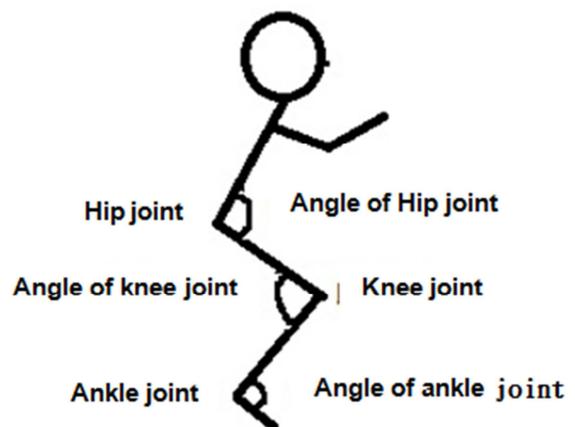


Figure 2. The lower extremity joint angles.

Table 1. The demographic data of the participants.

Participants	1	2	3	4	5	6	7	8	9	10	Average(M) \pm SD
Height (cm)	168	172	172	172	176	177	178	180	180	190	177 \pm 6.32
Weight (kg)	67	63	66	64	71	71	76	68	66	86	70.22 \pm 7.13
Experience (years)	9	9	10	10	7	9	11	7	7	5	8.4 \pm 1.83

2.2. Experiment Design

Before performing the experimental maneuvers, the participants were positioned three steps from the center of the force plates [16] as the approach distance. In the starting position, the participants faced the center of the force plates. When instructed to start, the participants performed a 72-cm attack three times. The participants performed the moving spike through their preferred approach and forward-jumping method, turned, and hit the target objects while in midair, landed through their preferred maneuvers, and immediately maintained a stable and balanced crouching position for 3 seconds (Figure 3).

After sufficient training, the participants began the official experiment while wearing shoes. Losing balance upon landing, landing upon the medial foot, performing additional small jumps, or shaking their upper body excessively upon landing were judged as a failure in execution; in such cases, the participants were required to repeat the jump-landing maneuvers until three attempts were successful.



Figure 3. Sequential front and side views of approach jump.

2.3. Experimental Instruments and Measurement

A total of 11 motion cameras (Motion Analysis Corporation, USA) were employed to record 3D images at an image-capture frequency of 200 Hz. A total of 27 reflective markers were attached to certain areas of the body to track the location of the joints. Two AMTI 90 × 60-cm² 3D force plates (AMTI Inc., USA) were used to record the ground reaction force at a sampling rate of 3,000 Hz.

EVa Real-Time software (Motion Analysis Corporation, USA) was employed to process the kinematic and dynamic

parameters. Noise in the reflective ball tracks and raw force plate data was removed using a 6-Hz low-pass filter. All the data acquired and analyzed pertained to the moment of landing. The kinematic and dynamic data included the changes in the hip, knee, and ankle angles after landing and were calculated using a joint coordinate system [17].

2.4. Statistical Method

SPSS Version 18.0 for Windows was employed for the statistical analysis with α set at 0.01 and 0.05. The demographic data of the participants underwent a descriptive statistical analysis. One-way ANOVA was conducted to compare the potential effects of the participants' body height, weight, and playing experience on the risk of kinematic and dynamic injury in the lower extremity joints.

3. Results and Discussion

Figure 4 illustrates the changes in the participants' joint angles during each sequence of the moving spike landing maneuvers. One-way ANOVA was conducted to identify the various effects of body height, weight, and playing experience on the kinematic and dynamic parameters, and least significant differences tests were used for a post hoc comparison of these parameters. The analysis results on the kinematic and dynamic parameters of the angles, angular velocity, and ground reaction force are as Figure 4.

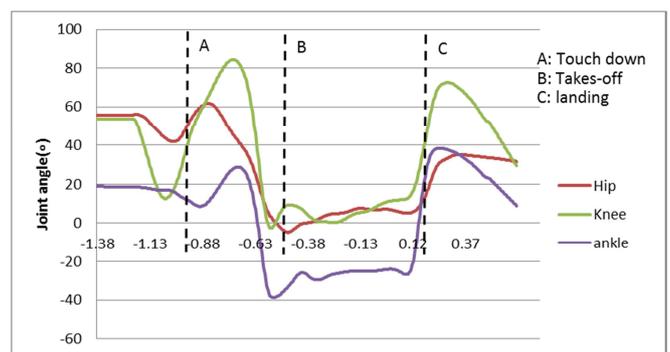


Figure 4. Joint angles during each sequence of the moving spike maneuvers.

3.1. Biomechanical Analysis of the Landing Sequences of the Participants with Different Heights

Table 2 lists the measured kinematic and dynamic data on the landing sequence after the participants, who had different heights, performed a moving spike. The post hoc comparison of the joint angles during the landing processes after the slide

attack is arranged in descending order as follows (each participant's height is followed by the joint angle in parentheses): 172 cm (21.19°) > 178 cm (13.38°) > 190 cm (9.64°) > 180 cm (7.59°) > 168 cm (7.21°) > 177 cm (5.71°) > 176 cm (5.11°). These results indicated that, compared with the other participants, the one who was 172 cm adjusted his hip joints to a greater extent to cushion his landing to reduce the ground reaction force and maintain balance. The heights (and average knee angles) of each participant in descending order according to their average knee angle were as follows: 172 cm (34.65°) > 180 cm (21.39°) > 176 cm (18.89°) > 178 cm (14.64°) > 177 cm (11.61°). These results indicated that, compared with the other participants, the 177-cm participant adjusted his knee joints to a greater extent for cushion landing to reduce the ground reaction force when landing. The height (and average ankle angles) of the participants in descending order according to their average ankle angles were as follows: 176 cm (-32.30°) > 168 cm (-14.18°) > 172 cm (-8.66°). This indicated that the 176-cm participant had the largest ankle joint angle. Generally, the lower extremity landing methods used by people in sports are distinguished according to the flexion angles of the knee joint. When the angle is smaller than 90°, the landing action is referred to as a soft landing; by contrast, when the angle is larger than 90°, the landing action is referred to as a stiff landing [9]. All of the participants in this study adopted a soft landing action and relied on the muscles on their knees and hip joints to absorb the impact force.

Table 2 lists the post hoc comparison of the momentary

angular velocity of the hip, knee, and ankle joints during the slide attack landing process. Only the momentary angular velocity of the hip joints differed significantly. On average, the height (and hip angles) of the participants in descending order of the hip angles were 172 cm (-9.66°) > 178 cm (-4.09°) > 180 cm (-4.05°) > 176 cm (-3.56°), and the difference in the average hip angles of the 172- and 176-cm participants was 6.10°. This indicated that the 172-cm participant bent his knee-joint to the largest angle shortly after landing, thereby enabling the muscles to rapidly stretch and contract during the action.

The post hoc comparison revealed significant differences among the participants in their slide attack ground reaction force data. Table 2 reveals that the moving spike generated a negative tibial shear force, which was regarded as lateral tibial shear force according to the experimental settings. The results indicated that the larger the shear force exerted on the tibia proximal to the knee joints is, the greater the ground reaction force and loading rates during landing increase the loading on the lower extremities and increase the risk of ACL injury [18]. The average negative tibial shear force generated by the participants is in the order of 172 cm (-5.33) > 180 cm (-3.38) > 178 cm (-3.07) > 190 cm (-2.41); the average horizontal reaction force generated by the participants is in the order of 172 cm (-1.93) > 180 cm (-0.93) > 176 cm (-0.91) > 190 cm (-0.87). We deduced that the 172-cm participant was at the highest risk of sustaining a collateral ligament injury from performing a moving spike.

Table 2. Kinematic and dynamic data of the participants with different heights.

Participants		168cm(A)		172 cm(B)		176 cm(C)		177 cm(D)		178 cm(E)		180 cm(F)		190 cm(G)		F	Comparison
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD		
Angle	Hip joint (°)	7.21	3.2	21.19	5.7	5.11	2.58	5.71	2.90	13.38	3.83	7.59	2.84	9.64	.84	12.31*	B>E>G>F>A>D>C
	Knee joint (°)	24.88	4.39	34.65	8.71	18.89	4.5	11.61	6.9	14.64	4.8	21.39	3.58	33.87	1.2	9.06*	B>F>C>E>D
	Ankle joint (°)	-14.18	4.87	-8.66	10.56	-32.30	5.53	-27.73	2.02	-26.62	.63	-20.64	3.82	-16.55	1.85	6.99*	C>A>B
Angular velocity	Hip joint (rad/s)	-4.41	1.75	-9.66	4.75	-3.56	.76	-6.13	.34	-4.09	.78	-4.05	.97	-6.81	.53	3.55*	B>E>F>C
	Knee joint (rad/s)	9.11	.44	10.22	3.08	7.68	.28	9.56	.72	11.44	.99	9.58	.56	9.02	.60	1.22	
	Ankle joint (rad/s)	-14.61	.55	-15.16	6.74	-14.07	1.24	-16.02	1.10	-16.77	1.49	-13.89	1.14	-14.29	1.19	.24	
Reaction force	Tibial shear force (B. W)	-4.35	.09	-5.33	.94	-2.82	.46	-3.85	.16	-3.07	1.64	-3.38	.46	-2.41	.66	8.35*	B>F>E>G
	Vertical reaction force (B. W)	9.26	.61	10.94	2.10	7.33	.42	8.05	.33	7.28	.36	7.60	.67	4.41	1.39	10.59*	B>D>F>C>E>G
	Horizontal reaction force (B. W)	-1.78	.51	-1.93	.53	-.91	.48	-1.67	.26	-1.54	.13	-.93	.31	-.87	.49	5.19*	B>F>C>G

*p<.01**p<.05

Table 3. Kinematic and dynamic data of the participants with different weights.

Participants		63kg(A)		64kg(B)		66kg (C)		67kg (D)		68kg (E)		71kg (F)		76kg (G)		86kg (H)		F	Comparison
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD		
Angle	Hip joint (°)	18.68	7.04	24.02	3.03	13.91	9.11	7.21	3.20	8.25	2.54	5.41	2.48	13.38	3.83	9.64	.84	4.91*	B>H>E>D>F
	Knee joint (°)	42.77	4.41	30.81	1.78	26.92	8.52	24.88	4.39	19.28	2.15	15.25	6.61	14.64	4.82	33.87	1.23	9.96*	H>E>F>G
	Ankle joint (°)	1.62	12.44	-17.74	1.77	-13.91	5.19	-14.18	4.87	-23.32	.70	-30.01	4.49	-26.62	.63	-16.55	1.85	12.78*	F>B>H>D>C
Angular velocity	Hip joint (rad/s)	-9.86	4.10	-5.61	.42	-8.76	6.12	-4.41	1.75	-4.07	1.53	-4.85	1.50	-4.09	.78	-6.81	.53	1.65	
	Knee joint (rad/s)	8.62	3.02	8.87	1.22	11.45	2.59	9.11	.44	9.43	.63	8.62	1.14	11.44	.99	9.02	.60	2.04*	C>F
	Ankle joint (rad/s)	-16.05	10.44	-13.00	.42	-14.84	5.33	-14.61	.55	-14.54	.65	-15.05	1.49	-16.77	1.49	-14.29	1.19	.22	
Reaction force	Tibial shear force (B. W)	-5.41	.63	-4.71	.54	-4.62	1.67	-4.35	.09	-3.41	.30	-3.33	.64	-3.07	1.64	-2.41	.66	3.12*	A>C>H
	Vertical reaction force (B. W)	12.80	.75	8.72	1.24	9.69	2.12	9.26	.61	7.14	.20	7.69	.52	7.28	.36	4.41	1.39	12.28*	A>C>D>B>F>G>E>H
	Horizontal reaction force (B. W)	-2.58	.25	-1.50	.16	-1.37	.47	-1.78	.51	-.81	.19	-1.29	.54	-1.54	.13	-.87	.49	5.35*	A>G>B>C>F>H>E

*p<.01 **p<.05

3.2. Biomechanical Analysis of the Landing Sequences of the Participants with Different Weights

Table 3 lists the weight and kinematic and dynamic data on the moment of landing after performing a moving spike for each participant. The participants' weight (and hip angles) after performing a moving spike, in descending order of their hip angles, are in the order of 64 kg (24.02°) > 86 kg (9.64°) > 68 kg (8.25°) > 67 kg (7.21°) > 71 kg (5.41°). Specifically, the 64-kg participant bent his hip joints more than the other participants did to cushion the landing to reduce the ground reaction force and balance his body. Arranging the average knee angles of the participants according the descending order reveals 86kg (33.87°) > 68 kg (19.28°) > 71 kg (15.25°) > 76 kg (14.64°). In other words, the 76-kg participant bent his knee joints more for cushion landing than did the other participants to reduce the ground reaction force and maintain balance. Regarding the average ankle angles, when arranged in descending order, the weight (and average ankle angles) of the participants were in the order of 71kg (-30.01°) > 64 kg (-17.74°) > 86 kg (-16.55°) > 67 kg (-14.18°) > 66 kg (-13.91°). These results indicated that the 71-kg participant bent his hip joints more than the other participants did to cushion the landing. On the participants' landing methods, the participants of various weights executed a soft landing after performing slide attack and used the muscles on their knees and hip joints to absorb the impact force.

Table 3 lists the post hoc comparison of the momentary

angular velocity of the hip, knee, and ankle joints during the slide attack landing sequence. Only the momentary angular velocity of the knee joints differed significantly. In particular, the average angular velocity of the 66-kg participant's knee joints was 11.45, and that of the 63-kg participant's knee joints was 8.62, yielding a difference of 2.83. This indicated that the knee joints of the 66-kg participant were bent at the largest angle shortly after landing, enabling the muscles to rapidly stretch and contract during the crouching sequence.

The post hoc comparison revealed significant differences among the participants' slide attack ground-reaction force data. Table 3 reveals that the slide attack generated a negative tibial shear force, which was a lateral tibial shear force. On average, the weight (and negative tibial shear force) generated by the participants was in the descending order of 63 kg (-5.41) > 66 kg (-4.62) > 86 kg (-2.41); the average horizontal reaction force generated by the participants were in the descending order of 163 kg (-2.58) > 67 kg (-1.78) > 76 kg (-1.54) > 66 kg (-1.37) > 71 kg (-1.29) > 86 kg (-.87) > 68 kg (-.81). We deduced that the 63-kg participant was at the highest risk of sustaining a collateral ligament injury from performing a moving spike.

3.3. Biomechanical Analysis of the Landing Sequences of the Participants with Different Playing Experiences

Table 4 lists the kinematic and dynamic data on the moment of landing after performing a slide attack according to the

participants' playing experience. Comparing the participants' playing experience (and hip angle when landing) after performing the slide attack, and arranging them in the descending order for hip angle revealed the order of 10 y (22.45°) > 9 y (10.53°) > 5 y (9.64°) > 7 y (6.77°). Specifically, the participant who had played volleyball for 10 y bent his hip joints more than the other participants to cushion the landing and reduce the ground reaction force and maintain balance. No significant difference was observed among the participants regarding their knee and ankle angles, all of which were smaller than 90°. Regarding the participants' landing methods, all of the participants, despite the differences in their playing experience, applied a soft landing after performing a slide attack and used the muscles in their knees and hip joints to absorb the impact force.

Table 4 lists the post hoc comparison of the momentary angular velocity of the hip, knee, and ankle joints during the slide attack landing action. Only the momentary angular velocities of the hip joints differed significantly. In particular, the average angular velocity of the knee joints of the participant who played volleyball for 10 y was -9.56, and that

of the participant who played volleyball for 7 y was -3.88, yielding a difference of 5.78. This indicated that the knee joints of the participant who played volleyball for 10 y bent at the largest angle shortly after landing, thereby enabling the muscles to rapidly stretch and contract during the crouching sequence.

The post hoc comparison revealed significant differences among the participants regarding their slide attack ground-reaction force data. Table 4 reveals that the slide attack generated a negative tibial shear force, which was a lateral tibial shear force. On average, the age (and negative tibial shear force) generated by the participants, arranged in the descending order for negative tibial shear force, was in the order of 10 y (-5.29) > 7 y (-3.20) > 11 y (-3.07) > 5 y (-2.41). On average, the horizontal reaction force generated by the participants was in the descending order of 9 y (-2.01) > 7 y (-.92) > 5 y (-.87). We deduced that the participants who had played volleyball for 9–10 y were at the highest risk of sustaining a collateral ligament injury from performing a moving spike.

Table 4. Kinematic and dynamic data of the participants with different playing experiences.

Participants		5yrs(A)		7yrs(B)		9yrs(C)		10yrs(D)		11yrs(E)		F	Comparison
		M	SD	M	SD	M	SD	M	SD	M	SD		
Angle	Hip joint (°)	9.64	.84	6.77	2.87	10.53	7.40	22.45	5.15	13.38	3.83	8.82*	D>C>A>B
	Knee joint (°)	33.87	1.23	20.55	3.84	26.42	14.32	30.58	7.36	14.64	4.82	2.82	
	Ankle joint (°)	-16.55	1.85	-24.52	7.12	-13.43	14.40	-13.80	4.63	-26.62	.63	2.57	
Angular velocity	Hip joint (rad/s)	-6.81	.53	-3.88	.89	-6.80	3.29	-9.56	5.41	-4.09	.78	3.45*	D>B
	Knee joint (rad/s)	9.02	.60	8.95	1.05	9.10	1.62	11.02	3.03	11.44	.99	2.31	
	Ankle joint (rad/s)	-14.29	1.19	-13.95	1.09	-15.56	5.30	-14.71	5.33	-16.77	1.49	.38	
Reaction force	Tibial shear force (B. W)	-2.41	.66	-3.20	.51	-4.53	.76	-5.29	1.12	-3.07	1.64	9.12*	D>B>E>A
	Vertical reaction force (B. W)	4.41	1.39	7.51	.58	10.04	2.19	10.02	1.94	7.28	.36	9.54*	A>B>D>C
	Horizontal reaction force (B. W)	-.87	.49	-.92	.35	-2.01	.53	-1.60	.22	-1.54	.13	10.07*	C>B>A

*p<.01**p<.05

4. Conclusion and Suggestions

4.1. Conclusion

1. When landing after performing a moving spike, the volleyball players in this study primarily used the muscles on their hip and knee joints to absorb the impact energy.
2. The ankle joint parameters generated by all of the participants when performing moving spike were negative, indicating that the participants' center of weight tended to deviate after landing. Regarding the ankle landing strategies, landing with a large flexion angle of the ankle plantar flexion enabled one participant to absorb the ground impact force and reduce the peak vertical ground reaction force. However, when the participants landed after performing a moving spike, their ankle joints generated negative data, and they were inhibited from utilizing ankle plantar flexion when

landing, which increased the ground impact energy. Consequently, the risk of ankle injury increased considerably.

3. This study involved observing the differences among the participants' landing data after they performed an actual jumping approach, turned, and hit a ball. The negative data generated from the lateral tibial shear force and horizontal ground reaction force indicate that when volleyball players continually perform attacking maneuvers that involve moving, jumping, and landing during training or competition without sufficient cushioning and protective equipment, they may develop chronic tendinitis in their collateral ligaments.

4.2. Suggestions

1. For volleyball players, injuries sustained from performing moving spike are due to insufficiently bending the lower extremities and being subjected to high ground reaction

force when landing, preventing the musculoskeletal systems of the lower extremities from effectively cushioning the impact energy. We suggest that the main muscles be strengthened and the ground cushioning time be prolonged to reduce the impact. In addition, players must improve the flexion angles of their knees and hips, wear protective equipment, and improve their body balance when landing to reduce the risk of chronic tendinitis from repeated and excessive impacts on the lower extremity joints in long-term training.

2. Coaches must specifically instruct players to adjust their landing positions, avoid stiff landing, and reduce the tibial shear force and horizontal ground reaction force generated from the lower extremity valgus to reduce the burden exerted on the muscles and ligaments on the players' lower extremity joints. In addition to preventing players from sustaining knee and ankle sprains, coaches must pay focus on preventing injury to the lateral ligaments. Thus, the risk of injury to the lower extremity joints, such as ACL and lateral ligament tears, can be lowered, and injuries from performing moving spike can be effectively prevented.
3. When players perform a slide attack at a greater height than normal, they must increase their knee and hip flexion angles when landing to reduce the ground reaction force and lower the likelihood of sustaining a lower extremity injury. In addition, players' knees and ankles should be equipped with protective equipment to further reduce the risk of injury from vibration and displacement of the knee and ankle joints. Appropriate protective measures can improve the performance of athletes and prolong their sports careers.
4. Numerous studies have indicated that abnormally stretching or rotating the lower extremity joints internally or externally, coupled with excessive load on the joints, increases the risk of lower extremity injury. However, measuring sports injuries is difficult because it requires athletes to actually perform high-risk experiments. Recently, methods and studies on calculating and simulating human musculoskeletal systems have increased, but few have examined the performance of moving spike. Therefore, the method and results of the present study provide a reference for researchers and coaches for future studies.
5. The results of this study cannot be generalized to female volleyball players or professional players. In addition, volleyball games involve various techniques. Additional studies can investigate the differences among the landing processes involved in various maneuvers, such as attacking, blocking, and jump-serving to clarify the landing techniques and the potential risks they involve.

In summary, professional volleyball techniques, kinematics, and academic theories on sports injuries should be applied in conjunction with objective scientific analyses to investigate the causes of lower extremity joint injuries. Thus, whether the injuries sustained by the lower extremity joints from slide

attacks are acute sports injuries or chronic damage can be clarified, and cushioning mechanisms can be effectively incorporated to prevent sports injuries to the lower extremity joints when performing moving spike.

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