Kinetical Analysis of Predictive Injury Parameters during Landing in Volleyball Players

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Abstract

Introduction: Kinetics parameters are known as some of the main reasons of volleyball injuries resulting from landing during performing various skills. Information about lower extremity kinetics in landing will help to understand characteristics of various injuries and develop injury prevention programs. So the aim of the present study was kinetical analysis of predictive injuries parameters during landing in volleyball players. **Materials and Methods:** Eighteen junior male volleyball players (Age: 17.78±0.94yrs) were asked to perform three maximal blockjump on a force platform. The data of force (F_{max}, F_{min}), impulse (I), loading rates (LR_{max}, $LR_{max-min}$), time to stabilization (TS), time to peak forces (T_{PF}) and time to maximum to minimum force ($T_{Fmax-min}$) variables were extracted andanalyzed .Pearson correlation coefficient (r) was employed to investigate possible relationship between kinetics and temporal landing parameters of block jump in participants. **Results:** The results showed significant correlations between some variables including F_{max} with LR_{max}, $LR_{max-min}$ and T_{PF}, F_{min} with TS, LR_{max} with F_{max}, $LR_{max-min}$ and T_{PF}, $LR_{max-min}$ with F_{max}, LR_{max}, T_{PF} and $T_{Fmax-min}$, TS with F_{min}, T_{PF} with F_{max}, LR_{max}, and $LR_{max-min}$, $T_{Fmax-min}$ with $LR_{max-min}$during landing in volleyball players. **Conclusion:**Biomechanists and sports injury expertise should monitor both of temporal and kinetic variables with respect to performance optimization as well as decreasing injury prevalence.

Keywords: Biomechanics; Injury; Kinetics; Landing; Volleyball

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Introduction

Although volleyball is considered as a non-contact sport, the prevalence of injuries are reported relatively high, especially with respect to the lower limb (1).Surprisingly, the incidence of acute injuries in volleyball is similar to the rates reported for more physically contact sports (2). In fact, the incidence of injury in volleyball is nearly equivalent to those observed in ice hockey and soccer (3).Regarding different joints and segments, it is also reported that approximately 65% of knee injuries in volleyball players were linked to inflammatory or overuse phenomena (4). Other epidemiological studies have reported prevalence of patellar tendinopathies of 40–50% in high-level volleyball (3, 5).

A review on the volleyball performance represented landing as one of the most frequent actions executing in various techniques such as spike, block and service (6). Accordingly, a number of previous studies have investigated about injury incidence in landing due to kinetic impressions including ACL damages (7-9), stress fractures, plantar fasciitis, patellar pain, osteoarthritis (10, 11), musculoskeletal injuries (12, 13).The combination of high ground reaction forces, rapid loading times, and the high frequency of jumping and landing during training sessions and games are thought to be significant determinants of volleyball injuries (14).

Kinetics parameters are known as some of the main reasons of volleyball injuries resulting from landing during performing various skills (7). Previous landing pattern analysis have shown relationships between types of pass, direction of movement, height of the jump, and position of volleyball players on the court (7, 15). Indeed, type of landing and subsequent movement after landing such as cutting or pivoting, stop and jump tasks in various direction may lead to increase the potential of serious risk of injuries (16). In this way, Watkins and Green (17)

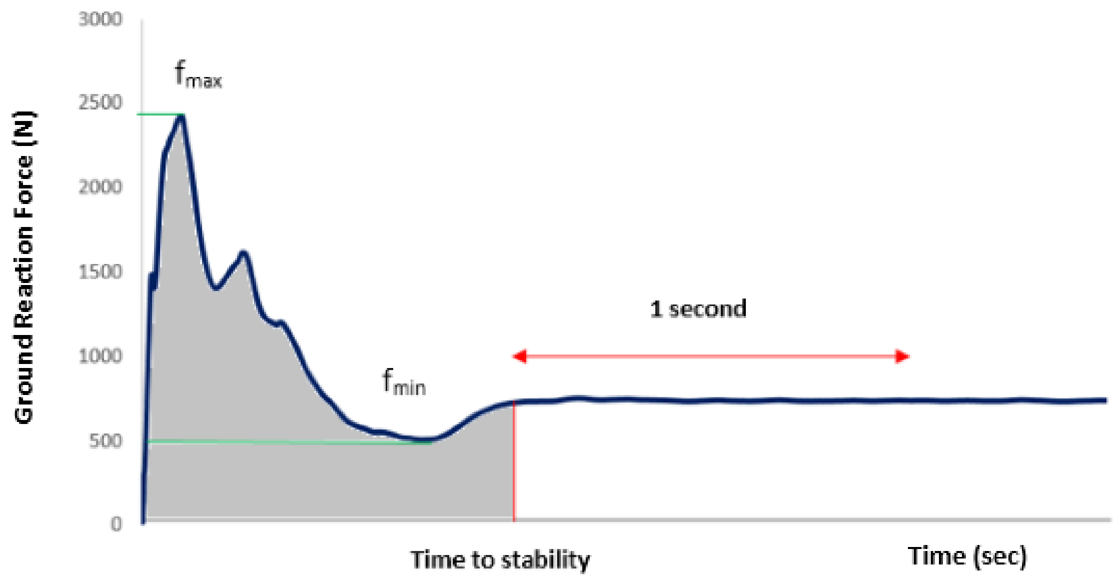

Figure 1. Landing Graph (the grey area represents Impulse)

reported that 15% of injuries occurred in the landing phase, while Cassel noted that 60% of acute injuries happened when landing after a block or attack with or without contact with another player (18). It is worthwhile to mention that landings often result in the certain of GRF on the order of five time body weight (19). So information about lower extremity kinetics in landing will help to understand characteristics of various injuries and develop injury prevention programs (20).

The most important kinetic factors in landing that is prominent in injuries include variables such as force (ground reaction effects that implies to volleyball players in contact with surface) (11, 14, 15), loading rates (slope of the ground reaction force curve in the vertical direction, until the first peak of force is reached) (21) and impulse (the area below the ground reaction force-time curve) (7, 15), as well as their temporal derivate, such as time to peak forces, time to stabilization (ability to maintain body balance when moving from dynamic to static within the base of support) (11, 15)were studies. For instance Zahradnik *et al.* and Cortes *et al.* (6, 7, 22) had some studied about GRF influence during landing after a block and also its relations with some injuries especially ACL damages.

Despite of these studies, best of our knowledge, there is no comprehensive study that focuses on correlations of these kinetic and temporal prediction injurie variables during landing in volleyball players and analysis their relations base of damage possibilities in lower extremities. Therefore, the aim of the present study was kinetical analysis of predictive injuries parameters during landing in volleyball players.

Materials and Methods

Participants

Eighteen junior male volleyball players were selected and participated in this study by convenience sampling method [Age: 17.78±0.94yrs, Weight: 773.19±59.86N, Height: 195.61±3.12cm, BMI: 20.21±1.46Kg.m^{-2} Mean (SD)]. They were excluded from study if they had any musculoskeletal or neurological deficit as well as any injury history that could influence Jumping biomechanics. Written informed consent was obtained prior to testing. The study followed the Declaration of Helsinki's recommendations. Testing procedure was performed in Olympic Laboratory and under supervision of volleyball federation of Islamic Republic of Iran (Code No.215; 07.01.2020).

Study design

The study design was quasi experimental.The athletic task tested in this study was Block jump (23-25). At the beginning of the test, warm up protocol was performed individually for 15 minutes according to official condition of the volleyball training sessions or games. The athletes were encouraged to jump “as high as possible”. For each subject, three to five times practice were allowed to be more familiar with the appropriate procedure of the test. For minimizing coach role no verbal instructions was described for players. Data collection started with the calibration of the force platform system (Kistler® force platform with sampling rate of 1000 Hz). Participants were asked to perform three maximal block jump and between each trial one minute rest was considered. The data of force (maximum and minimum),

Table 1. Descriptive measures of kinetics and temporal variables in landing

Variables	Mean (SD)
F_{max} (BW)	3.38(0.88)
F_{min} (BW)	0.63 (0.13)
I (N.S)	0.36 (0.03)
LR_{max} ($BW.S^{-1}$)	46.91 (24.27)
$LR_{max-min}$ ($BW.S^{-1}$)	4.96 (2.25)
TS (S)	1.86 (0.94)
T_{PF} (S)	0.08 (0.03)
$T_{Fmax-min}$ (S)	0.60 (0.15)

Maximum Force (F_{max}, Minimum Force (F_{min}), Impulse (I), Maximum Loading Rate (LR_{max}), Maximum to Minimum Loading Rate ($LR_{max-min}$), Time to Stabilization (TS), Time to Peak Force (T_{PF}), Time of Maximum to Minimum Force: ($T_{Fmax-min}$)

impulse, loading rates (maximum and maximum to minimum), time to stabilization, time to peak forces and time to maximum to minimum force variables for the best block jump trial were exported and then analyzed in MATLAB programs software (Math Works Inc., Cambridge, MA, USA).

Data Analysis

For data analyzing Force-time curve derived directly form force plate output in vertical direction. The curve contains three separate phase, jumping, flight time and landing. Initiation of the landing phase was considered after flight time when the subjects touch the force plate and the magnitude of the vertical force components exceed over 10 N. In this phase in order to calculate force, impulse, loading rates, and temporal variables the following procedures were done according to landing graph (Figure 1) (11, 26-28):

- Maximum Force (F_{max}): The highest peak of force derived from force plate output in landing phase normalized to the body weight.
- Minimum Force (F_{min}): The lowest peak of force derived from force plate output in landing phase normalized to the body weight.
- Impulse (I): The area below the force – time curve of landing from contact to stability.
- Maximum Loading Rate (LR_{max}): The ratio of the body weight normalized maximum landing force to time form contact to maximum force.
- Maximum to Minimum Loading Rate ($LR_{max-min}$): The ratio of body weight normalized maximum force minus minimum force to time between maximum and minimum force.
- Time to Stabilization (TS): The interval between contact time and the instance that the measured force will remain constant at least for one second on the force plate.
- Time to Peak Force (T_{PF}): The interval between contact and time of maximum force
- Time of Maximum to Minimum Force: ($T_{Fmax-min}$): The interval between time of the maximum and minimum peak of force in landing.

Statistical analysis

Statistical analysis was performed with SPSS Version 21.0 statistic software package. To check the normality of variables distribution, Shapiro-Wilk' test was performed. Statistical descriptive are shown as means (SD) in Table 1. Pearson product moment correlation coefficient (r) was employed for the analysis of the relationship between kinetics and temporal landing parameters of block jump in participants. Statistical significance was set at $P<0.05$ and $P<0.01$ levels according to Pearson Table.

Results

Results of Shapiro-Wilk test showed that the data distribution was normal in all variables of the study. Descriptive measures of kinetics and temporal variables during landing are shown in Table 1.

Table 2 demonstrates the correlation coefficients between principle variables of study. As it can be observe, there are significant correlations between F_{max} with LR_{max}, $LR_{max-min}$ and T_{PF}, F_{min} with TS, LR_{max} with F_{max}, $LR_{max-min}$ and T_{PF}, $LR_{max-min}$ with F_{max}, MLR, T_{PF} and $T_{Fmax-min}$, TS with F_{min}, T_{PF} with F_{max}, LR_{max}, and $LR_{max-min}$, $T_{Fmax-min}$ with $LR_{max-min}$.

Discussion

The aim of present study was kinetical analysis of predictive injuries parameters during landing in volleyball players. The results showed there are significant correlations between some variables including F_{max} with LR_{max}, $LR_{max-min}$ and T_{PF}, F_{min} with TS, LR_{max} with F_{max}, $LR_{max-min}$ and T_{PF}, $LR_{max-min}$ with F_{max}, MLR, T_{PF} and $T_{Fmax-min}$, TS with F_{min}, T_{PF} with F_{max}, LR_{max}, and $LR_{max-min}$, $T_{Fmax-min}$ with $LR_{max-min}$ during landing following block jump in volleyball players.

To the best of our knowledge there is no scientific document regarding correlation between kinetic variables that are mainly related to injury in a specific sports skill. Landing, as mentioned, is a complex skill that could be considered as a critical performance in volleyball players and should be investigated due to its harmful properties (16). While landing done, ground reaction force causes internal loads that can impress lower limbs and make them susceptible to various injuries (14),so the magnitude of GRF during landing is considerable for biomechanical scientist and sports injury specialists Results of the present study are in consistence with Bates *et al.* which reported greater side to side asymmetry in vertical ground reaction force during impact of landing, a vital cause of ACL injury risk factor (29).

Table 2. Correlation coefficients between kinetics and temporal variables in landing

Variables	F_{max} (sig)	F_{min} (sig)	I (sig)	LR_{max}(sig)	$LR_{max-min}$ (sig)	TS (sig)	T_{PF} (sig)	$T_{Fmax-min}$(sig)
F_{max}(BW) (sig)								
F_{min}(BW) (sig)	0.22 (0.37)							
I (N.S) (sig)	0.35 (0.15)	0.23 (0.34)						
LR_{max} ($BW.S^{-1}$) (sig)	0.95 (0.00)**	0.23 (0.34)	0.33 (0.18)					
$LR_{max-min}$ ($BW.S^{-1}$) (sig)	0.82 (0.00)**	-0.09 (0.71)	0.13 (0.60)	0.80 (0.00)**				
TS (S) (sig)	-0.09 (0.72)	-0.48 (0.04)*	-0.32 (0.18)	-0.042 (0.86)	0.12 (0.62)			
T_{PF}(S) (sig)	-0.60 (0.007)**	-0.15 (0.53)	-0.04 (0.86)	-0.73 (0.001)**	-0.53 (0.02)*	-0.03 (0.88)		
$T_{Fmax-min}$ (S) (sig)	-0.31 (0.21)	0.27 (0.27)	0.09 (0.71)	-0.31 (0.20)	-0.76 (0.00)**	-0.23 (0.35)	0.23 (0.35)	

*Maximum Force (F_{max}), Minimum Force (F_{min}), Impulse (I), Maximum Loading Rate (LR_{max}), Maximum to Minimum Loading Rate ($LR_{max-min}$), Time to Stabilization (TS), Time to Peak Force (T_{PF}), Time of Maximum to Minimum Force: ($T_{Fmax-min}$); ** Significant Correlations (P<0.01); * Significant Correlations (P<0.05)*

Ours investigated correlation of two important derivate of GRF in landing *i.e.* minimum and maximum forces with other kinetical and temporal parameters. We found a positive relations between Fmax with LRmax (r=0.95, *P*=0.00) and LRmax-min (r=0.82, *P*=0.00). No specific study was found regarding relationship between force and loading rate during landing. Loading rate is the ratio of maximum landing force to time form contact to maximum force (27). So maximum force shows district effect on the quality and quantity of loading rates and these positive relations arecompletely logical. Also as loading rate is a proportional of maximum force time occurrence, the more loading rate increases, the more force will be tolerated upon lower limb and therefore maybe the injuries prevalence are more possible. On the other side, between F_{max} and TPF (r=-0.60, *P*=0.07) negative relation was observed. It should be noted that higher forces would occur in lesser time's interval. Landing type is also an important parameter in defining mentioned relations. Hard landing with higher maximum force would result in lower time to peak as well. The task in the present study was block jump and obviously players after landing from a block should be ready for further skills such as counter attack or block again. Landing following block jump is mainly of the hard landing type and may cause more injuries in compare with soft landings so this invers relation between F_{max} and TPF is explainable. While landing occurs, due to GRF enter to lower limb, adduction moment and knee valgus creation is common, and it is one of the most causes of ACL injuries (7). Based on these outcomes, maybe we can conclude that, spending less time for landing, would predispose players to more ACL injuries.

Based on the results of the present survey there was a negative significant relation between F_{min} and TS(r=-0.48, *P*=0.04). Minimum force or second peak of force (F2) occurs when the player's heels contact with surface in landing (6) and this instance, is the initiation of time to stabilization phase, so these two variables are ordered following each other. Since the longer time to stabilization duration occurs, the players may find the stability and balance later and minimum force can acts as an external factor to creation constancy, the less minimum force requires more time to stability for balance situation after landing. Increasing the time to stabilization would lead to more injuries due to less balance status (28), therefore it is important to control minimum force and TS parameter for preventing injuries especially in ankle joints like ankle instability.

Maximum loading rates showed positive significant relations with another loading rate deviate i.e. maximum to minimum loading rate (r=0.80, *P*=0.00). Since both of these parameters are cognate, this finding seems to be acceptable. As mentioned before, loading rate is a parameter representing direct association with maximum force and is a ratio of time to peak force occurrence. This equation approves the fact that the shorter time to peak force, the higher maximum loading rates. In the other word, loading rate needs lower time to reach to its peak. In conclusion the negative relations of LR_{max} and $LR_{max-min}$ with TPF (r=-0.73, *P*=0.001 and r=-0.53, *P*=0.02 respectively) is logical and since time to peak force increases, the players are exposed to less injury due to lower loading rate magnitude. Because in loading rate both force and time are prominent, and force occur along with time, various chronic and acute injuries may be created and damages drive to inner muscle tensions and sprains.

Concerning temporal variables of the present study, as discussed earlier, time to peak force showed negative correlations with maximum force and maximum loading rates and also time to stabilization revealed negative relation with minimum force. Also $TF_{max-min}$ displayed negative significant relationship with $LR_{max-min}$ (r=-0.76, *P*=0.00). Thus, maybe it can be infer that, temporal variables would cause fewer injuries due to their negative and invers relations with principle kinetical variables in landing. So the higher the time of skill performance, the less force and consequently less damages would be considered.

Impulse is known as a product of kinetic and temporal variables, calculating as the area under the force – time curve landing from contact instance to stability (26). Therefore it can influence on both contact and stability models during landing and also the injuries related to changing this variables. Some investigations are available regarding the effects of clinical interventions on impulse quantity, for instance Hosseini *et.al.* studied about the effects of arch support insole on impulse during Landing (30) or Valizadehorang *et.al.* investigated about the effect of using a knee brace on impulse during landing in athletes with ACL injuries (31). But no distinct survey was conducted regarding correlation of impulse and other kinetic- temporal parameters during landing. Based on the results of our study there was no significant relationship between impulse and other mentioned variables. Maybe the negative relation between temporal and kinetic variables would justify the results, and on the other hand impulse represents a range, instead of a certain point, and mainly it depends on the proportion of time and force in a constant situation. Whilst increasing one would be neutralized by decreasing the other's effect. As impulse can apply sudden force in a limited time and occur frequently during playing, stress fracture and tendinopathies are known to be of the most prevalent injuries resulting by impulse (26), it is noticeable that mentioned injuries can be modify by performance and landing's technique optimization.

More investigations are needed to clarify different aspects biomechanical injuries in different tasks in volleyball. One of the most important limitations of this study was the few number of participants. More investigations concentrating on various aged-groups in different genders or different skills' level are recommended.

Conclusion

Based on the analysis of the present study, we can conclude that temporal and kinetic parameters have negative relation with each other concerning injury incidence. But according to the repetitive and continuous nature of volleyball jumping and landing skills during the training and competitions, increasing time of landing is inevitable, therefore coaches or athletes should consider and focus on other parameters that could modify landing kinetics, including power, muscle strength, type of exercise and etc. Also should monitor both of temporal and kinetic variables with respect to performance optimization as well as decreasing injury prevalence.

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Authors' contributions:

All authors made substantial contributions to the conception, design, analysis, and interpretation of data.

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