Biomechanical Analysis on the Stop-jump Action of Patients with Knee Joint Injury

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Abstract: *Stop-jump requires many efforts at knee joint. This study aims at analyzing the biomechanical characteristics of stop-jump action of patients with knee joint injury through testing the biomechanical indicators when the subjects doing stop-jump action. Sixty students were selected from Zhengzhou Professional Technical Institute of Electronic & Information, Henan, China and divided into a control group, a unilateral injury group and a bilateral injury group according to the screening results of knee joint injury. The physical quantities such as duration of rising to the air, the rotation angle, flexion and extension angle and adduction and abduction angle of the hip joint and the inclination angle of the pelvis in the experiment of stop-jump action were calculated through motion experiment, imaging analysis method and Ariel Performance Analysis System (APAS). It was concluded from the experiment that the pelvis, hip joints and ankle joints suggested compensatory phenomenon and bore more moment produced during motion of human body instead of the injured knee joints. The compensation can offer a great opportunity for the prevention of knee joint injury and damage management.*

Keywords: *Knee joint injury, Stop-jump, Biomechanics, Basketball.*

Introduction

Knee joint with its complex structure is extremely easy to be damaged. Acute injury of knee joint may be induced by directly striking knee, abnormal bending or falling down on knees. There are more than one million cases of acute knee injury in Emergency Department of North America every year and fifty thousand person-times of knee injury that need surgery in America [6]. Though knee joint problem is usually induced by one or more injures, other reasons are still possible. Some people are more likely to have problems in knee joints than other people. Moreover, exercise, entertainment activities, aging and diseases such as osteoporosis and arthritis can increase the risks of knee joint injury.

An epidemiological investigation [8] suggested that knee joint injury accounted for 14% to 33% among all injuries (chronic knee joint injury: 25%; acute knee joint injury: 8%) and the incidence frequency of knee joint injury was quite high (eight in a thousand). In the past twenty years, anterior cruciate ligament (ACL) injury suggested a surprising increase among young female athletes who take part in sports involving jumping and rotation [13]. The incidence of ACL of youth and female adults who take part in such sports is eight or nine times higher than that of male adults who take part in the same sports. The study [16] found that most of patients with knee joint injury which was not induced by sports or other factors are aged from 51 to 70 years.

Meniscus injury is common among athletes and ordinary people. Edwards et al. [5] claim that the cumulative risk of ACL injury among patients who age from 10 to 64 years was about 5% and surgery induced meniscus injury was 15% at least according to MRI results of acute knee injury. The incidence of ACL is unknown. However, the incidence of ACL was reported as 81/100,000 in a hospital research [14] and 50% to 100% in population-based studies. Therefore, effective biomechanical analysis on knee joint injury is important and necessary. In this study we are reporting the results from an experimental investigation of patients with knee joint injury, aiming to provide a reference for the prevention and treatment of athletes with knee joint injury.

Materials and methods

Selection of research subjects

Students who play basketball were selected from Zhengzhou Professional Technical Institute of Electronic & Information, Henan, China. Those who had severe injuries such as anterior cruciate ligament, fracture or patellar dislocation, once underwent lower limbs surgery, had diseases in lower limbs except knee joint injury, were difficult to move, or had pain on other sites of lower limbs except knee joints were excluded [1] to ensure the effects of other symptoms on the experiment. Sixty subjects were screened out according to the above criteria, registered, numbered and recorded. The height and weight of the subjects were measured and recorded. Then they were examined by senior orthopedists; the acute and chronic injuries were not identified. Clinical diagnostic basis included presence of pain on knee joints, swelling or malformation on knees, slightly effects on activities of lower limbs and pressure points in joint space. Finally 28 subjects were diagnosed as unilateral knee joint injury, including 12 cases of left knee injury and 16 cases of right knee injury; 17 subjects were diagnosed as bilateral knee joint injury; 15 subjects had no injuries on knees. The subjects were divided into three groups, a control group (healthy knees), a unilateral injury group and a bilateral injury group (Table 1). Each subject should fill out a questionnaire which included the background, dominant leg, history of injury and history of illness. The subjects with injured knee joints filled out an additional Victorian Institute of Sports Assessment (VISA) scale under the guidance.

Table 1. Baseline conditions of the subjects

Group	**Number of cases**	**Age, years**	**Height, cm**	**Weight, kg**	**Body mass index (BMI)**	**Training years, year**
Control group	15	21.03 ± 1.04	185.33 ± 5.68	80.36 ± 9.75	23.54 ± 2.66	6.48 ± 1.97
Unilateral injury group	28	20.15 ± 1.33	187.56 ± 7.25	79.94 ± 12.56	23.69 ± 2.19	6.21 ± 2.08
Bilateral injury group	17	20.08 ± 1.21	184.76 ± 8.69	83.75 ± 11.37	23.88 ± 2.46	5.76 ± 1.89

Note: BMI = weight/height^2

Experimental methods

Requirements on stop-jump action

To ensure safety and make the body state of the subjects closer to the good state after warming up in formal training, the subjects were asked to do warming up for 10 to 20 minutes before experiment. The action of stop-jump included two parts, i.e. low-speed run-up and sudden stop after one-step transition. The speed should remain unchanged during single-foot transition [12]; two arms should swing upward and vertically as possible; the feet were required to reach the largest height after takeoff. The actions of takeoff and landing require two feet stepping on two force platforms respectively. The length of run-up track was 10 m. To ensure the accuracy of the experiment result, each subject performed experimental motor task five times; the data obtained in three standard actions in which complete reflection markers were displayed were taken to prevent large deviation caused by improper action.

Test on stop-jump

Before test, the subjects wore unified tight jackets and shorts, swimming caps and non-reflective, low-cut, non-air cushion sports sneakers. Sixteen reflection markers of were pasted on the anterior superior spine (ASIS), upper leg, lateral condyle of femur, lateral anklebone, heel and second metatarsal bone by professional staffs, as shown in Fig. 1. After warm-up, the subjects did the action of stop-jump under the explanation and demonstration of professional staffs. Moreover an infrared high-speed camera with a sampling frequency of 200 Hz was used to collect kinematical images [2]. AMTI force plate was synchronous with ViconTM Motion system to determine the initial contact in the landing stage [11]. Eight Kistler 9281CA three dimensional force platforms (Switzerland, specification: 600 mm × 400 mm × 35 mm) were used to collect and process the dynamics indexes; data acquisition frequency was 1000 Hz.

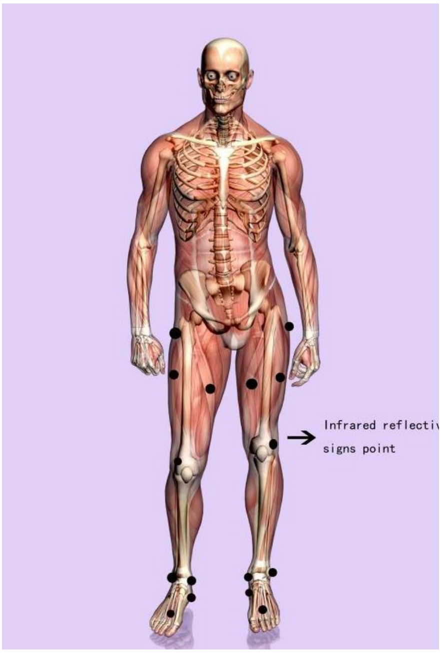

Fig. 1 The position of the infrared mark points

Dynamics indexes

The measured parameters from the experimental data were:

- duration of the platform touching – this was the time from landing on the three-dimensional force platform to takeoff;
- duration of rising to the air – this was the time from takeoff to the second time of landing on the three-dimensional force platform;
- inclination angle of the pelvis – this was the angle between the pelvic plane of inlet and horizontal plane;
- rotation angle of the pelvis – this was the angle between the original plane of the pelvic and the plane after the pelvis rotating towards the inner and outer sides of the upper legs;

- flexion and extension angle of the hip joints – this was the angle between the femur and tibia, and the decrease of the angle was called extension, and the increase of the angle was called flexion;
- adduction and abduction angle of the hip joints – this was the angle between the location of the hip joint after moving inward and outward and the original location of the hip joint;
- rotation angle of the hip joints – this was the angle between the plane in which the hip joints located after rotation and the vertical plane;
- flexion and extension angle of the ankle joints – this was the angle between the horizontal plane and the plane in which the ankle joints located when landing;
- adduction and abduction angle of the ankle joints – this was the angle between the location of the ankle joints after moving inward and outward and the original location of the ankle joints;
- rotation angle of the ankle joints – this was the angle between the plane in which the hip joints located after rotation and the vertical plane.

Calculation of muscle moment

Moment of force referred to the tendency of a force to make an object rotate in the aspect of physics. Firstly unknown interference which was induced by force of friction and chemical transmission resistance was excluded. The computational formula of moment of force was $M = L \bullet F$, in which, M stands for the moment of force produced by muscle (unit: M), L stands for the distance vector from axis of rotation to origin of force, and F stands for the vector force generated by muscle. Distance vector could be calculated based on the angle of joints and the relative movement distance of joints during sports. Vector force could also be calculated out based on the force measured using instruments and angle function.

Image analysis

The collected images were analyzed using Ariel Performance Analysis System (APAS). Firstly the motion images were edited and rearranged using the system, and then a coordinate system was established. The system analyzed several infrared reflective characteristic points in the images, demarcated coordinates, made smoothing processing on the coordinate data, and eliminated errors. Then the display application of APAS system calculated out the kinematic quantities such as the flexion and extension angle, adduction and abduction angle, rotation angle and moment of force according to the coordinate values of the characteristic points. The so calculated parameters were stored for further analysis.

Statistical analysis

Experimental data were expressed as mean ± standard deviation (SD). Comparison between groups was performed using one-way analysis of variance. Post-hoc test was performed using least significant difference method. SPSS ver. 17.0 was used. Difference was considered as statistically significant if $p < 0.01$.

Results

Duration of action and VISA score

Stop-jump needs sudden stop. As the take-off action produces large impacts on the stability of joints, the changes of strength or angle of the lower limbs can weaken or disperse pressure on knee joints. In the process of landing, joints such as the pelvis, knee and ankle determine the posture of up and down due to the influence of ground reaction force. The test results demonstrated that there was no remarkable difference between the groups after the action of stop-jump was completed. The VISA score of the control group was 100 ± 0, which was significantly different with that of the injury group (Table 2).

Table 2. Comparison of the reaction time of stop-jump and VISA indicators

Item	Control group	Unilateral injury group	Bilateral injury group
Number of people (n)	15	28	17
Duration of platform touching, s	0.42 ± 0.18	0.53 ± 0.14	0.55 ± 0.22
Duration of rising to the air, s	0.32 ± 0.05	0.29 ± 0.04	0.26 ± 0.05
VISA score (point)	100 ± 0	75.37 ± 11.27**	75.12 ± 12.79**

Note: * refers to $p < 0.05$ and ** refers to $p < 0.01$ compared to the control group.

Location and angle of the pelvis

In contrast to the control group, there was a large pressure on the knee joints in the unilateral injury group, and there was a very significant statistical difference between the bilateral injury group and the unilateral injury group in the inclination angle of the pelvis ($p < 0.01$). The results demonstrated that the extensor muscle moment of the subjects with bilateral knee joint injury decreased. To reduce the injury on the knee joints, the inclination angle of the pelvis was adjusted. The subjects in the control group kept a proper forward position, which was beneficial to the full force exerting of the lower limbs. The changes of bending angle and extension angle of the pelvis were basically the same with the moment of landing (Table 3). Contrary to retroversion of pelvis in the control group, the pelvis of the injury groups inclined backward. It indicated that the body inclined backward at the moment of landing to relieve the impacts of ground vertical reaction force on the injured knee joint. It indicated that adjusting the inclination angle of the pelvis could compensate the injured knee joints.

Table 3. The changes of angles of anteversion, retroversion, left and right inclination and rotation of the pelvis

Position of the pelvis, (°)	Control group	Unilateral injury group	Bilateral injury group
Anteversion and retroversion	124.68 ± 132.27	-85.67 ± 165.39**	-94.26 ± 143.35
Left and right inclination	-13.35 ± 5.97	-13.96 ± 6.08	-14.67 ± 4.19
Rotation angle	93.24 ± 6.84	97.25 ± 2.16*	101.33 ± 4.75

Note: * refers to $p < 0.05$ and ** refers to $p < 0.01$ compared to the control group.

Variation characteristics of the hip joint

The adduction angle of the hip joint and the angle of the pelvis rotating towards the inner side of the upper legs increased when the subjects in the bilateral knee injury group fulfilled landing, which was remarkably different with the control group ($p < 0.01$). Table 4 demonstrates that the injury severity changed with the angle change of the hip joint, and the change of joint angle developed gradually. The hip joint of the subjects in the bilateral knee joint injury group had obvious changes in the movement of coronal plane. Through the compensatory changes of the joints, the flexion, extension and rotation of the hip joint and knee joint induced by ground vertical acting force was increased. Knee injury resulted in dysfunction, and the hip joint compensated the knee joint; however, such compensation could further aggravate knee injury.

Table 4. Changes of the hip joint angles

Angle, (°)	Control group	Unilateral injury group	Bilateral injury group
Flexion and extension angle	-33.64 ± 10.03	-38.68 ± 7.35	-44.9 ± 3.71
Adduction and abduction angle	-1.97 ± 3.56	1.46 ± 3.88**	3.27 ± 4.52
Rotation angle	4.68 ± 3.49	6.01 ± 4.52	4.5 ± 7.94

Note: * refers to $p < 0.05$ and ** refers to $p < 0.01$ compared to the control group.

The external force moment produced by the ground reaction force carrier was resisted by the muscle and non-contractile tissue such as ligament and joint capsule [15]. Generally, the orientation of ground reaction force vector relative to united center determines the direction and size of moment of the knee [7]. The position of body mass center relative to pressure center could affect the ground reaction force vector. As the position of body mass center was seriously affected by the mass of body [4], the abnormal movement of the pelvis and trunk might affect the direction of ground reaction force vector and finally affect the moment on the knees.

Variation characteristics of ankle joint angle

Table 5 demonstrates the abduction angle in ankle joint in the injury groups and the adduction angle in ankle joint in the control group, but the direction was opposite; the rotary moment of the ankle joint of the control group was significantly different with that of the injury groups ($p < 0.05$); the extorsion moment in the control group and the intorsion moment in the injury groups were the opposite and the moment of flexion and extension and the moment of adduction and abduction of the ankle joints had remarkable difference.

Table 5. Change of ankle joint angle

Angle, (°)	Control group	Unilateral injury group	Bilateral injury group
Adduction and abduction angle	-0.9 ± 3.5	-1.6 ± 2.4	-0.08 ± 3.2
Flexion and extension angle	34.5 ± 6.9	33.7 ± 8.1	38.2 ± 16.5
Rotation angle	-4.2 ± 2.4	-3.34 ± 2.8*	-3.1 ± 4.6

Note: * indicated $p < 0.05$ and ** indicated $p < 0.01$ compared to the control group.

Knee joint injury could induce the changes of the angle of the coronal plane of the ankle joints. The higher the severity, the larger the abduction angle, and vice versa. Therefore, it could be concluded that the change of abduction angle of the ankle joint changed due to the severity of knee joint injury, and the change was slow and progressive. To inhibit the abduction of the knee joint, the abduction angle of the ankle joint was increased to relieve the load on the knee joint and compensate the injured knee joint.

The research results demonstrated that the extension torsion of the left leg was not increased after the right knee was injured. The phenomenon was caused by uneven strength of the left and right legs, larger strength of leg muscles or the physiological cross difference of muscle fibers. Therefore, the compensation for the peak of the vertical reaction force of ground moment was to increase knee extension moment.

On the basis that the abduction moment was compensated, external force was exerted on the knee joints to disperse moment while the patients with bilateral knee joint injury was landing, but the effect of rotation torque compensation might increase the instability factors of the knees and ankle joints because it damaged the stability of the original knee joints. To control or relieve body shiver during landing, the patients adjusted posture subconsciously to change the flexion and extension for compensation. Moreover, the unilateral or bilateral knee joint injury weakened the stability of the ankle joint and increased the rotation moment or abduction moment.

Conclusion

Through analysis on the above results, it is concluded that the patients with knee joint injury changed the inclination and rotation angles of the pelvis because of the presence of ground vertical reaction force while leaving the ground and landing [10]. To adapt to force exerting, the patients with unilateral knee joint injury were compensated by increasing the abduction angle of contralateral hip joint. To compensate the patients with bilateral knee joint injury, the torque of the knee joint was increased; as to the patients with unilateral knee joint injury, the extension moment of the contralateral limb or the abduction joint of the knee joints was increased. Hence patients with early knee joint injury can increase the abduction angle of the ankle joint to relieve the compression on outward knee joints and burden on the knee during landing and buffering.

Timely examination is necessary before the progress of knee joint injury. Strict evaluation methods for surgical and conservative treatment are needed in treatment. The proven neuromuscular and biomechanical measures should also be used [3]. In view of the success of neuromuscular plans in changing the risk factors and incidence of knee injury, similar motion strategies can be used to relieve the development of injury [9]. The biomechanical analysis on the action of stop-jump of patients with knee joint injury provides a great opportunity to the prevention of knee joint injury and injury management.

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