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ORIGINAL ARTICLE

LOWER LIMB VALGUS ALIGNMENT COMPARED WITH TWO- AND THREE-DIMENSIONAL MOTION ANALYSIS DURING A DROP JUMP TEST

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Abstract Two- and three-dimensional motion analysis methods are commonly used for the measurement of dynamic lower limb alignment. However, there has been very few comparative studies between these two methods. The purpose of the present study was to investigate the correlation of the biomechanical data between two- and three-dimensional motion analysis methods for the evaluation of dynamic knee alignment. Seven female and 7 male college basketball players were recruited to perform a drop jump test. The Knee/Hip ratio for evaluation of valgus alignment of the knee in the coronal plane was measured by a two-dimensional motion analysis system with a digital video camera. The joint kinematics and kinetics of the knee were evaluated by a three-dimensional motion analysis system. From toe touch to maximum knee flexion, the knee/hip ratio decreased significantly both in males and females. However, the knee valgus angle and the peak knee valgus moment were not correlated with change in the knee/hip ratio. Both males and females showed a similar change in the knee/hip ratio in the two-dimensional motion analysis during the drop jump, but significant differences in joint kinematic and kinetic patterns were seen in the three-dimensional motion analysis. These differences should be taken into account when using the two different motion analysis systems.

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Key words: motion analysis; dynamic lower limb alignment; kinetics; kinematics.

原　著

2次元および3次元動作解析法を用いたジャンプ着地動作中の下肢外反アライメントの比較

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抄録　2次元および3次元動作解析法は動的下肢アライメントの計測に良く用いられている．本研究ではジャンプ着地動作を2次元動作解析法と3次元動作解析法を用いて同時に計測し，2つの方法の関係を調べた．大学バスケットボール選手男女各7名を対象とし，着地動作に続いて最大垂直跳びを行なわせた．ビデオカメラ1台を用いた2次元動作解析法では，接地から最大膝屈曲に達するまでに男女ともに冠状面における下肢外反変化を認めた．同時に計測した3次元動作解析法では，男性よりも女性において有意に大きな膝外反モーメントと膝外反角度を認めた．しかし，2次元動作解析法と3次元動作解析法との間には有意な相関関係は認めなかった．2次元動作解析法は簡便な計測法であるため大規模な調査などに対して有用な調査法である．しかし，2次元動作解析法と3次元動作解析法との違いについて注意を払い用いる必要があると考えられる．

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INTRODUCTION

Anterior cruciate ligament (ACL) injury is a common and traumatic knee joint injury which often occurs in noncontact situations[1, 2]. Additionally, in sports such as basketball, soccer and handball, female athletes have been reported to be 2 to 8 times more likely to sustain a noncontact ACL injury than male athletes involved in the same sports[1−4]. It is a serious injury that can curtail an athlete's career, therefore, much attention has been paid to the prevention of noncontact ACL injuries in recent years. Various biomechanical studies have been performed to analyze the onset mechanism of noncontact ACL injuries, but it has not yet been clarified. Video analysis at the time of injury appear to show that the mechanism is forceful valgus collapse combined with external or internal rotation of the tibia, and so this lower limb position is considered a risk factor of ACL injuries[2, 3, 5]. In addition, motion analysis of the dynamic lower limb alignment in sports movement has been performed. Three-dimensional motion analysis is one technique often used to evaluate the kinetics and the kinematics of the lower limbs. Hewett et al. used this method in a prospective study which that the showed knee valgus angle and knee valgus moment during drop jump tasks could be predictive factors of ACL injury risk in female athletes[6]. On the other hand, Noyes et al. developed a simple and easy two-dimensional motion analysis system using a digital video camera, and evaluated the dynamic lower limbs alignment and analyzed the medial knee motion which occurred during drop jump tasks in the coronal plane[7] (Fig. 1). They measured the separation distance between the right and left hip and normalized separation distances between the knees with the hip separation distance, which was used as a parameter of the medial knee motion in the coronal plane. They reported that after neuromuscular training, the normalized knee separation distance was improved and the medial knee motion was decreased to a more neutral lower limb alignment during drop jump tests. These two-dimensional or three-

Fig. 1 Photograph showing medial knee motion (white arrow).

dimensional motion analysis methods are generally used for evaluation of dynamic lower limb alignment during sports tasks, however, both methods have disadvantages. Although the three-dimensional motion analysis system is an ideal technique to evaluate dynamic lower limb alignment, it raises considerable financial, spatial and time-requirement difficulties, which severely limit its application in screening tests or studies with a large sample size. On the other hand, because two-dimensional motion analysis is a simple and easy method, it is useful in large-scale screening for risk factors associated with ACL injury. However, there have been few reported research that has examined the correlation of the two-dimensional and the three-dimensional motion analysis systems. Therefore, the relation between valgus lower limb alignment in the coronal plane as seen by the two-dimensional motion analysis method and both lower limb kinetics and kinematics data which can exert loading on the ACL have remained unelucidated.

The purpose of this study was to compare lower limb valgus alignment during drop jump tests in both two-dimensional motion analysis, and kinetics and kinematics data of knee joint in three-dimensional motion analysis. We hypothesized that:

(1) when the medial knee motion in the coronal plane is presented by two-dimensional motion analysis, the valgus knee is seen in three-dimensional motion analysis.

(2) there are statistical correlations between the account of the medial knee motion in the coronal plane by two-dimensional motion analysis and knee valgus angle and peak knee valgus moment by three-dimensional motion analysis,

(3) females show greater values of valgus alignment both in two-dimensional and three-dimensional motion analysis compared to males.

To test these hypotheses, we simultaneously evaluated lower limb alignment with two-dimensional motion analysis and the kinematic and kinetics of the knee joint with three-dimensional motion analysis.

MATERIALS AND METHODS

Subjects

Seven male and 7 female college basketball players agreed to participate in this study. Subject inclusion was based on the lack of any surgical history and subjective symptoms of the lower limbs. The mean age of the female subjects was 20.7±2.3 years (range, 18-24 years), and the mean age of the male subjects was 22.3±3.7 years (range, 20-28 years). The experiment was approved by the Ethics Committee of the School of Medicine, Hirosaki University.

Test protocol

All subjects were allowed unlimited time for self-directed warm-up and stretching. The subjects were asked to complete one drop jump test in which they were instructed to drop off a box with 35 cm height, land on both feet on the force plates (model OR 6-7; Advanced Medical Technology, Inc, Watertown, MA), and then immediately perform a maximum vertical jump. Each subject was allowed to practice the task until he or she felt comfortable performing it. No instructions regarding jumping techniques were given to the subjects to avoid a coaching effect on their performance. The data were simultaneously obtained by the two-dimensional and three-dimensional motion analysis systems.

Data Collection

Two-dimensional motion analysis

Two-dimensional motion analysis was performed using a video camera system according to the techniques described by Noyes[7]. A digital video camera (30Hz; HDR-HC3, Sony Products, Japan) was placed on a 100 cm high tripod 4 m from the box. Reflective markers 25mm in diameter were secured with double-sided adhesive tape on the skin at the greater trochanter (Hip marker) and the center of the patella on both the right and left legs of all subjects. By advancing the video frame by frame, the following images were captured as still frames: (1) Toe touch (TT), which was defined as the point at which the toes just touched the force plates after the jump off from the box; and (2) maximum knee flexion (MKF), which was defined as the point of maximum knee flexion. The captured images were imported into the hard drive of a desktop computer and digitized on the computer screen using software (Frame-DIAS II, DKH, Japan). We measured the separation distance between the right and left hip markers and measured the separation distance between the right and left knee markers. Normalized knee separation distance (the knee/hip ratio) was calculated as the knee separation distance/hip separation distance.

Three-dimensional motion analysis

Kinematic and kinetic data were collected by a three-dimensional motion analysis system with seven cameras (VICON, Oxford Metrics, London, England). At a sampling rate of 120 Hz the data from the two force plates (model OR 6-7; Advanced Medical Technology, Inc, Watertown, MA) were sampled at 1200 Hz and time synchronized to the VICON system. Both static and dynamic calibrations were performed, and residuals of less than 2 mm from each camera were deemed acceptable. According to the VICON Clinical Manager protocol 25 mm diameter reflective markers were secured with double-sided adhesive tape on the skin positioned over the anterior superior iliac spine, posterior superior iliac spine, lateral midthigh, lateral femoral condyle, lateral midcalf, lateral malleolus, posterior calcaneus, and the second metatarsal head of each lower limb.

The three-dimensional marker trajectories recorded and calculated kinematic variables with a VICON Workstation (version 4.6; Oxford Metrics, London, England). Kinematic variables of interest included knee valgus at TT and MKF. Inverse dynamics analyses were used to calculate knee joint varus-valgus moments from kinematic data and force plates data. The force plates data were filtered through a low-pass Butterworth digital filter at a cutoff frequency of 50 Hz. The peak knee valgus moment during the interval from TT to MKF was determined and normalized by the subject's body weight (kg) and height (m).

Statistical analysis

We calculated statistical means and standard deviations for each variable. Two-way ANOVA and unpaired Student's t-tests were used to determine whether significant differences existed between the motion phases (TT and MKF) and genders, respectively. Spearman's rank correlation test was used to determine whether significant correlations existed between the knee/hip ratio and the average value of three-dimensional kinematic and kinetic data from both legs. For all analysis, a p value of 0.05 was used to denote statistical significance. Statistical analysis was performed using SPSS statistical software, version 12.0 (SPSS Inc, Chicago, IL).

RESULTS

The knee/hip ratio

From TT to MKF, the knee/hip ratio decreased from 0.99±0.07 to 0.77±0.12 in males and from 0.73±0.12 to 0.48±0.13 in females, indicating presence of medial knee motion and increase of the valgus lower limb alignment in the coronal plane (Fig. 2).

Kinematic data

Positive values represent knee valgus positioning. In males, the knee valgus angle decreased from −7.7±6.2° to −10.0±8.4° but

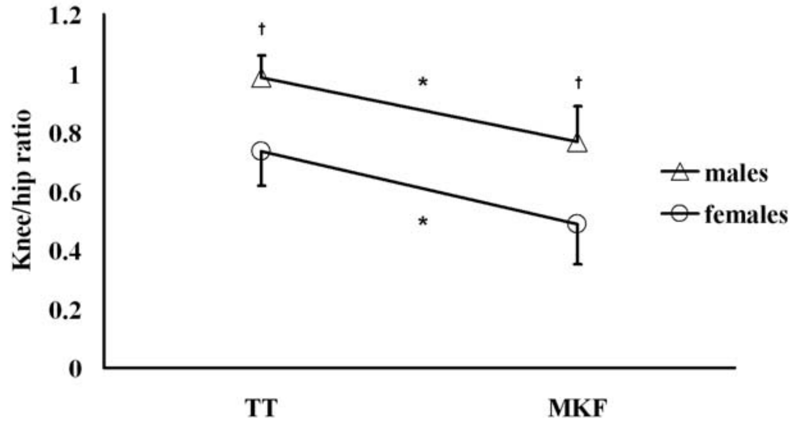

Fig. 2 Change in the knee/hip ratio from TT to MKF. Note the significant differences in the knee/hip ratio between TT and MKF and also significant differences in the knee/hip ratio between males and females.

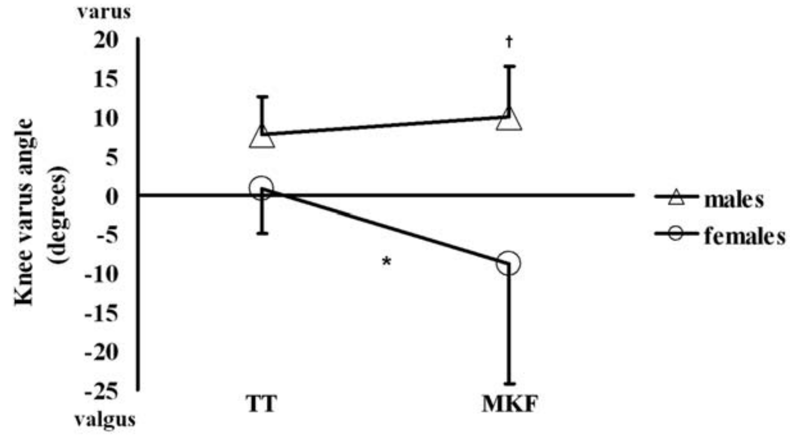

Fig. 3 Change in knee varus angle from TT to MKF. A significant difference in change of valgus from TT to MKF in females is seen, As is the significant difference in the change of knee varus between males and females.

without a significance (p=0.54) (Fig. 3). In females, the knee valgus significantly increased from 0.4±2.7° to 8.0±7.1° (p<0.01) (Fig. 3).

A significant gender differences was seen in the knee valgus angle (p=0.01) at MKF and in the knee valgus angle at TT (p=0.01).

Peak knee valgus moment

The peak knee valgus moment from TT to MKF was 6.7±8.6 N m kg^{-1} m^{-1} in males and 10.0±4.9 N m kg^{-1} m^{-1} in females (Fig. 4). Females showed a significantly larger value (p=0.04) than males.

Correlation between two-dimensional and three-dimensional analysis

There was no statistical correlation between the knee/hip ratio as determined by the two-dimensional motion analysis and kinematic value of the lower extremities as determined by the three-dimensional motion analysis (p=0.16, r=0.39) (Fig. 5). Furthermore, there was no

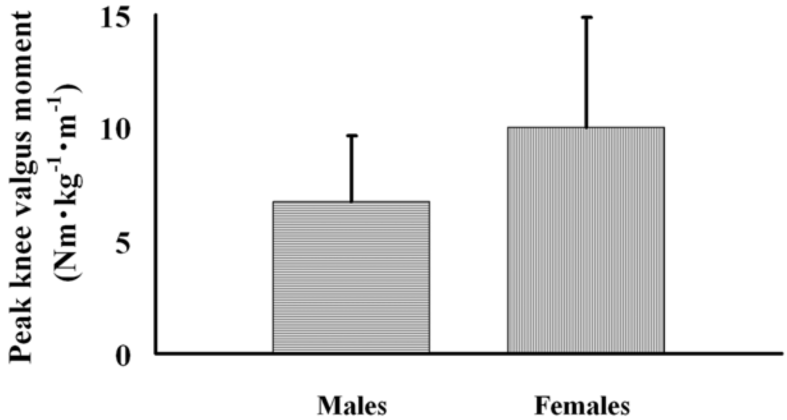

Fig. 4 Comparison of peak knee valgus moment. A significant difference in the peak knee valgus moment between males and females is shown.

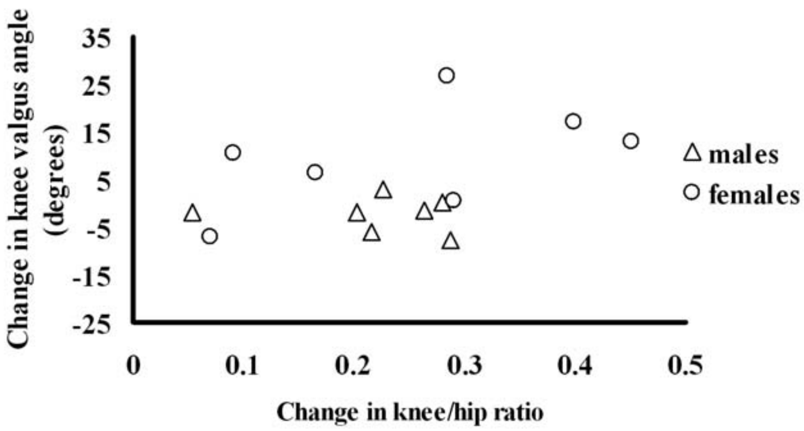

Fig. 5 Association of knee valgus angle at MKF and change in the knee/hip ratio, showing no correlation between them.

statistical correlation between the knee/hip ratio in the two-dimensional motion analysis and kinetic parameters of the knee joint in the three-dimensional motion analysis (p=0.58, r=−1.60) (Fig. 6)

DISCUSSION

The first hypothesis of this study was that when medial knee motion in the coronal plane was presented by the two-dimensional motion analysis, valgus knee would be seen in the three-dimensional motion analysis. Although males and females both presented medial knee motion in the coronal plane, males did not present any significant increase in knee valgus from the TT to MKF, whereas females presented significant increase in knee valgus from the TT to MKF. Our first hypothesis was proved in females, but was not validated in males.

The second hypothesis was that there would be statistical correlations between the account of the medial knee motion in the coronal plane assessed by two-dimensional motion analysis and knee valgus angle and peak knee valgus moment assessed by three-dimensional motion analysis. But we found no statistical correlations, and our

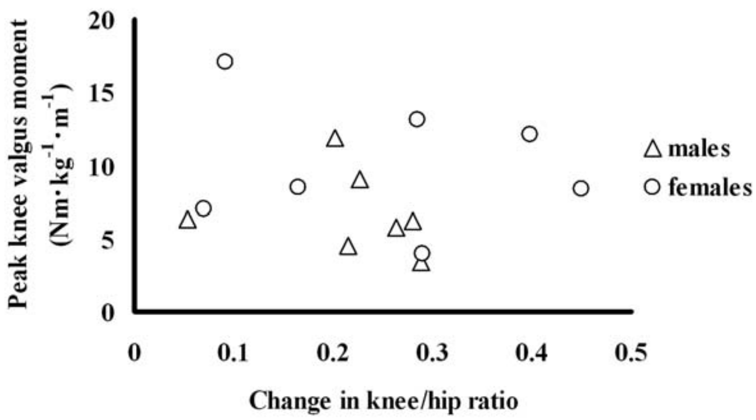

Fig. 6 Association of the peak knee valgus moment and change in the knee/hip ratio. No correlation was seen between these factors.

second hypothesis was not validated, either in males or in females.

The third hypothesis was that females would show greater values of valgus alignment compared to males both in the two-dimensional and the three-dimensional motion analysis. In the two-dimensional motion analysis, females showed a significantly larger knee/hip ratio compared to males and in the three-dimensional motion analysis, females showed significantly larger values in both knee valgus angle and peak knee valgus moment compared to males. Our third hypothesis, therefore, was proved.

Noyes et al. reported that the knee/hip ratio decreased from TT to MKF both in females and males, and there were no statistical significant differences between genders[7−9]. In our results, the knee/hip ratio decreased similarly but there were statistically significant differences between genders. The difference between our results and those in the past reports might be caused by the differences in the subject number, age, and race.

In joint kinematics of the knee, females showed a significant increased change in knee valgus, whereas males did not. In the three-dimensional motion analysis, Ford et al. reported that females showed a larger knee valgus angle during landing tasks compared to males[10], and Yu et al. reported that females showed valgus knee whereas males showed varus knee during stop jump tasks[11]. A similar result was demonstrated in our study. In a previous study, increasing valgus positioning by five degrees from neutral alignment can increase the load on the ACL by six times[12]. Our results that males showed lower varus position and females showed a larger valgus angle at MKF, may help to explain the sex disparity in ACL injuries.

Several biomechanical studies which described the knee valgus moment reported that females showed a larger knee valgus moment compared to males during sports tasks[13−15]. The knee valgus moment is thought to be a risk factor for ACL injuries as it subjects the ACL to increased strain[6, 16, 17]. The present study showed larger knee valgus and valgus moment in female subjects compared to male subjects, indicating increased risk of ACL injury in females.

These gender differences of knee joint kinematics and kinetics might be due to frame size, muscle strength, muscle activation pattern, and skill levels[10, 13, 15, 18, 19]. In this study we did not evaluate these factors, therefore further research is necessary to elucidate what roles, if any, they play.

There were no statistical correlations

between the knee/hip ratio and knee valgus angle at MKF and peak knee valgus moment in our study. It is thought that the medial knee motion in the coronal plane as seen by the two-dimensional motion analysis could consist of multi-directional joint motion: knee varus/valgus, hip adduction/abduction and hip internal/external rotation, for example, suggesting a disadvantage of the two-dimensional motion analysis. When we evaluate lower limb alignment of a large numbers of athletes, two-dimensional motion analysis is more convenient than three-dimensional motion analysis, but we must be fully aware of its demerits when using it.

There are some limitations of this study. Small sample size was used in this study. And we did not evaluate the hip and ankle kinetics and kinematics. Further work is needed to better understand the relationship between two- and three-dimensional motion analysis.

CONCLUSION

During drop jump tasks, females showed valgus lower limb alignment, thought to be a risk factor for ACL injuries, compared to males both in the two-dimensional and three-dimensional motion analysis. In terms of valgus lower limb alignment, however, there were no statistical correlations between the results of the two-dimensional motion analysis and those of the three-dimensional motion analysis. Before the using two-dimensional motion analysis, a through understanding of the differences between it and three-dimensional motion analysis is required.

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