Original article

A new method of hip joint moment's evaluation

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Abstract

Joint moments play very important role in biomechanical research related to lower limbs. Three–dimensional motion analysis is widely used in clinical decision making and sport biomechanics. The accuracy of joint moments is particularly important for data analysis. If the joint moments are not accurate, it will mislead the clinical judgment. However there is no method to verify the accuracy of joint moments. To assess the reliability of the joint moments, a new method should be developed. So a new method based on the principle of the transfer between mechanical lower limb work and potential energy was developed. Five healthy student volunteers participated in the study. The motion data were collected and were processed using VICON motion analysis system. The lower limb work and the potential energy were calculated and compared in four kinds of hip joint centre location estimation models. Using the new concept, one of the four models showed the least difference between the potential energy increase and mechanical work. With this concept, the model in which the most accurate joint moment can be calculated was identified. However, given that these techniques are commonly used in the motion analysis laboratory set by researchers and clinicians, more investigations are needed in order to upgrade laboratory setting and joint center prediction methods.

Introduction

Three–dimensional (3D) motion analysis is widely used in clinical decision making and sport biomechanics [1, 2]. The accuracy of joint moments is particularly important for data analysis. If the joint moment is not accurate, it will mislead the clinical judgment. Stagni et al [3]. showed that inaccuracies in the Hip joint center (HJC) co-ordinate estimates affect moments at the hip and knee to a different extent. They found that among the lower limb joint moments the hip joint moments showed the largest propagation error [3]. However there is no method to verify the accuracy of joint moment.

So new method should be developed. We propose a new method using the energy conservation principle. In physics, there is energy conservation principle in which the mechanical

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work done is equal to the increase of the potential energy. Our method is to apply this principle to a human body motion. When a human body produces mechanical energy by using the joint moment power, the total work done by all the joints in the body will produce the increase of the potential energy which can be calculated by looking at the center of gravity height. When all the joint moments in a body are accurate, the work equals to the increase of the potential energy. However it is very hard to consider all the joints moments at the same time. So we consider only the hip joint moment at the first step to verify our new concept. We select a motion in which only the hip joint moments are activated to increase the center of gravity height where the knee work and the ankle work are assumed to be almost zero.

When considering the hip joint moment, the joint center estimation error has more effect on the calculation. The HJC location depends on the method used. There are several models for HJC estimation. For example the Data Interface File Format of Clinical Gait Analysis Forum of Japan (DIFF) model, Plug in gait (PIG) model, the symmetrical centre of rotation estimation (SCoRE) model [4] and three dimensional rotational (3DR) estimation model [5]. We therefore chose these four models because the DIFF method is often used in Japan, PIG method is world widely used, SCoRE method is newly developed and 3D rotational method was developed by one of the authors. The purpose of this study was to use our new method to judge the accuracy of the joint moments by considering several hip joint location estimation methods.

Materials and Methods

1. Experimental procedures

Coordination of space and ground reaction force defined the x -axis as right positive, y-axis as forward positive and z-axis as upward positive. Before collecting subject's data, we conducted accuracy tests for the three dimensional motion analysis system cameras and the force platforms in the laboratory.

1) Accuracy test of cameras

Two tests were performed for the cameras. One test was done at the distance between two markers and the other at the angles formed by three markers position.

The first accuracy test was conducted following the accuracy test methods presented in previous studies [6, 7]. The 3D camera accuracy measurement test consisted of a stick bar on which a marker was attached at each end. A 700 mm distance between markers was measured with a measurement tape and was reported as the true value. First, the measurement accuracy in the vertical direction was determined. A tester was asked to hold the stick bar so that his forearm was parallel to his torso. Then the tester, by maintaining an upright stance, walked sequentially in the walkway provided as described in previous studies [6, 7]. In the present study the tester walked only in the force platform area (3 m by 0.6 m).

Next, the measurement accuracy in the walking direction was determined. The tester walked while holding the stick bar parallel to the sagittal and horizontal planes, and was moving it in the vertical direction around the middle of his thigh. The tester was instructed not to walk out of the walkway provided [6, 7].

Finally, the measurement accuracy in the medio-lateral direction was determined. The tester walked while holding the bar in front of him, keeping parallel to the coronal and horizontal planes, and was moving it in the vertical direction above and below the middle of the thigh [6, 7]. The movements in all planes were taken five trials with the same subject. To evaluate the noise, the stick bar was placed (longitudinal axis in the direction of motion) in the walkway area in order to take the static data. To prevent reflections contributing to the noise a book with 10 mm thickness was placed under the stick bar.

2) Evaluation of the angles

An “L” type metallic ruler which has 90° angle was prepared to measure the angle (the second test) accuracy. To prevent reflections contributing to noise, the metallic ruler was wrapped up with adhesive tape. Then three reflective markers were placed respectively at the 90° angle, at the 440 mm and at 240 mm distance of each upright forming the 90° angle. The same tester was instructed to walk holding the metallic ruler in the vertical direction, medio-lateral direction and in the direction of motion. The tester performed three trials in each direction.

3) Accuracy of centre of pressure (COP) of each force platform

Before taking the subject data, the calibration of two force platforms was conducted. A male tester was asked to put his weight vertically on various parts of each of the two force platforms using a wooden sandal with a ball point at the sole as described in a previous study [8]. About 90 trials and other 9 validation trials were taken.

4) Data analysis for 3D camera system

A computer program was used to calculate the average values and standard deviations (SD) for all trials taken in the horizontal plane, sagittal plane and the frontal plane. The second test concerning the angle’s data taken from the metallic ruler were processed. The angle was calculated from three reflective markers on the “L” type metallic ruler.

5) Data analysis for COP accuracy test

A computational program was developed using Matlab as described in a previous study [8] to calculate the position of the COP before and after the calibration. With a motion capture system, a computational program was used to calculate the contact point of the ball point with the force platform. The 90 points trials were used to create the correction table. The correction vectors were used in the correction table to correct the position of the COP data of each force platform.

2. Subject preparation

Our testing subjects consisted of five healthy male student volunteers, with respective average age of 21 years old, height and weight of 168 cm and 55.6 kg. The subjects approved their consent to this study and the approval from the Ethics Committee of Niigata University of Health and Welfare was obtained (Approval No: 17889). Subjects were dressed in a tight suit. Then the anterior superior iliac spines (ASIS) and posterior superior iliac spines (PSIS) were located. A total of 49 reflective markers were set on the subject before taking the data (Figure. 1). Markers were placed following the marker setting protocol of Plug-in-Gait method and DIFF manual, Gait Analysis Forum of Japan [9]. The markers at the hip side were placed at the right and left anterior superior iliac of spine, right and left posterior superior iliac of the spine, the right and left point of the proximal two-third of the line from the greater trochanter to the anterior superior iliac spine. Prior to the joint motion data collection, the static data was collected. All components of floor reaction forces were reset to zero before the subject stood on the force platforms to eliminate offset of the force data before initiating each experimental trial.

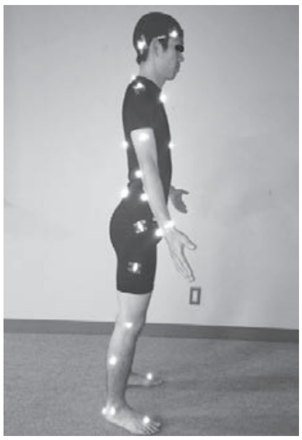

Figure 1. Marker setting on the subject.

1) Movement description

The subjects were in the standing position before performing the movements.

(1) Task 1

The participant was asked to perform Pelvis rotation in a circular motion for the 3D rotational model and a combined motion of flexion/extension and abduction intercepted by the neutral position for the SCoRE [4] movement.

(2) Task 2

Subject was told to stand upright on the two force platforms. One foot was placed on one force platform and another foot on the other force platform. Then the subject was instructed to bend the trunk forward at approximately 40° from the standing position. Next, the subject extended the trunk from 40° forward to standing position. Finally the data were taken from trunk bending position to a standing position (Figure. 2). All the Kinematic data were collected with 12 motion capture system cameras (VICON, Oxford Metrics, UK) at a sampling rate of 100 Hz. Two AMTI (Advanced Mechanical Technology Incorporation, USA), force platforms collected data simultaneously at 1 KHz. In order to calculate the mean and SD values, four trials were taken for analysis for one subject and ten trials for other subjects.

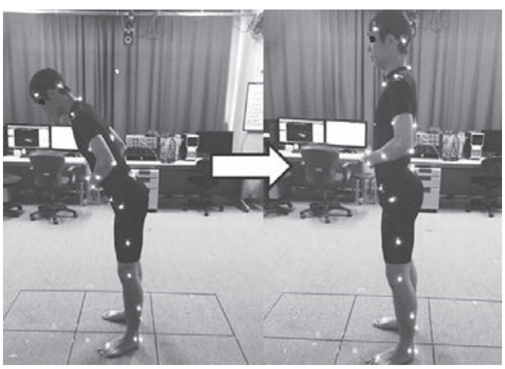

Figure 2. Subject extending trunk from bending position to standing position in Task 2 motion.

2) Data analysis for the subject

(1) The data for Task 1

The Task 1 data which consisted of multiple movements of the hip joint were processed. Then the HJC prediction used in previous methods such as the SCoRE [4] and the three dimensional rotational models [5]. The three dimensional rotational method determined the hip joint centre position from three markers set on the lower limb. A point at which the displacement of the local coordinate system of the pelvis becomes minimal when moving the lower limb is considered as the hip joint centre position [5].

(2) The data for Task 2

The data for task 2 were processed using "Bodybuilder" software. Firstly, the position of the centre of gravity (CoG) of the subject was calculated based on the anthropometric data [10]. The change position of CoG from 40° trunk bending forward to neutral position was calculated. And the height of CoG was multiplied by the body mass and the acceleration of the gravity to determine the potential energy. Secondly the lower limb joints moments were calculated. Then the lower limbs joints moments were multiplied by the angular velocity to determine the joints power. The sum of all joints power was integrated to determine the lower limb mechanical work done by the subject from trunk bending forward at about 40° position. The HJC estimated in the different methods was used in Task 2 motion to calculate the potential energy and mechanical work. Finally, the difference between the potential energy and the mechanical work was calculated. The task 2 motion has been chosen because the motion described in task 2 did not involve other joints of lower limb expect the hip joint.

Results

The results for the data concerning the distance for accuracy were shown in Table 1:

Mean values of the absolute errors in distance between the markers were 4.1 mm, 4.2 mm and

4.2 mm for vertical, antero-posterior and medio-lateral respectively.

Maximum = maximum values of the distance between two markers were 697, 696 and 696 mm

Minimum = minimum values of the distance between two markers were all 695 mm.

Noise = maximum SD of the data for two markers for all three coordinates was 0.04 mm.

Then the error related to the angle = Average-90° (Table 2) were 0.1°, -0.2° and -0.4°.

The results for COP before the calibration of the force platform 1 and force platform 2 show the maximum difference of 8.9 mm and 14.7 mm respectively for COP data taken from the motion capture device and COP data taken from the force platforms. After the calibration, the maximum difference was reduced to 4.7 mm and 2.5 mm respectively.

The results for task 2 are shown in Table 3 for comparison. The 3D rotational method showed an average of -1.8 J of difference when comparing the potential energy and the mechanical work, while the SCoRE and the DIFF methods averaged 2.7 J and 2.9 J respectively. The maximum difference seen was -6.2 J for the PIG method and the 3D rotational method showed less difference.

Table 1. Results from the accuracy test of the 12 cameras concerning the distance. (mm)

Direction	True value (mm)	Max (mm)	Min (mm)	Average (mm)	SD (mm)	Ave.Abs (mm)
Vertical	700	697	695	696	0.4	4.1
Antero-posterior	700	696	695	696	0.2	4.2
Medio-lateral	700	696	695	696.2	0.4	4.2

Max (Maximum), Min (Minimum), SD (Standard Deviation), Ave. Abs (Average of Absolute Value).

Table 2. Results from the accuracy test of the 12 cameras concerning the angles. (degree)

Direction	True value (degree)	Average (degree)	SD (degree)	Error (degree)
Vertical	90	90.1	0.4	0.1
Antero-posterior	90	89.8	0.3	-0.2
Medio-lateral	90	89.7	0.3	-0.4

Table 3. Results of comparison of potential energy and mechanical work for all the five subjects.

Direction	3DR Work (J)	DIFF Work (J)	SCoRE Work (J)	PIG Work (J)
Difference Mean	-1.8	2.9	2.7	-6.2
Difference SD	2.8	3.3	5.2	2.5

Figures 3 to 7 show the mean and SD values of the potential energy and lower limb work for the four methods; 3DR, DIFF, SCoRE and PIG respectively. Figure 8 shows mean values of the relation between the potential energy and the mechanical work for the trials in the four methods for one subject. And figure 9 shows results of the difference between the potential energy and mechanical work for all the five subjects for the four methods.

Discussion

In the accuracy test for the laboratory setting, the parameters related to the system performance that might cause errors in the data analysis such as: the distance, the angles and the center of pressure were assessed. These parameters were measured in different directions in order to evaluate the maximum error and the noise (SD from 0.2 to 0.4 mm) related to the 12 cameras and 2 force platforms used in this study. The maximum error of the camera was 4.2 mm (Table 1). The calibration method for the two force platforms described in this study allowed the reduction of 2.5 mm to 4.7 mm error related to COP data. This accuracy test was done because in order to validate hip joint moment, the motion capture system coordinate and the force platforms coordinate should correspond to each other beforehand.

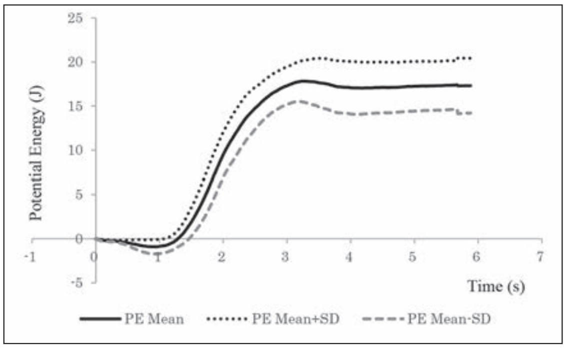

Figure 3. Mean value and SD of Potential Energy (PE) for one subject.

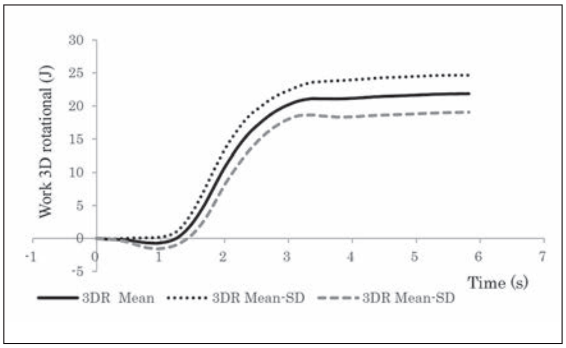

Figure 4. Mean value and SD of Work for 3D rotational model (3DR) for one subject.

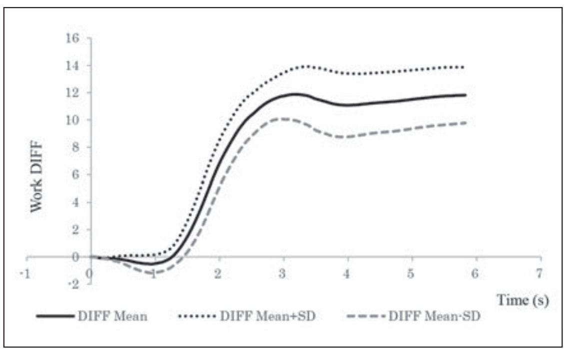

Figure 5. Mean value and SD of Work for Data Interface File Format (DIFF) for one subject.

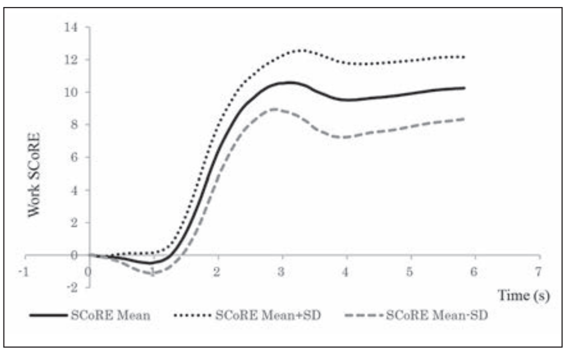

Figure 6. Mean value and SD of Work for Symmetrical Centre of Rotation Estimation (SCoRE) for one subject.

Previous studies have documented on the lower limb joint center location based on predictive or image methods [11-17]. In addition several methods were used in estimating the HJC, whether based on the geometric center or regression techniques [18, 19]. However these studies have not identified any method to verify whether the calculation of the hip joint moment is accurate or not. The present study highlighted the evaluation method of HJC location prediction based on the comparison of potential energy and mechanical work to verify the hip joint moment accuracy. Considering the fact that the mechanical work done by the subject should be equal in amount to the increase of potential energy under the condition that the motion stopped at the end. But if there were errors in the data measurement and processing, then that condition would not be satisfied. Analysis in the hip joint have been conducted because previous study (Stagni et al. [3]) showed that the error related to the hip moments compared to the knee was larger. Therefore evaluation at the hip has been considered in this study. So the motion of task 2 was designed that the subject can move trunk from bending position to neutral position only by the hip joint motion. This motion allowed the change of centre of gravity position. Thus the change in center of gravity position from at about 40° forward to neutral position enabled the calculation of the increase of potential energy of the subject. The DIFF approach which predicts HJC at 18% medially from the point of the proximal two-third of the line from the greater trochanter to the anterior superior iliac spine showed a difference of 2.9 J when comparing the potential energy with the mechanical work. The PIG approach showed -6.2 J, the SCoRE approach showed 2.7 J and the 3D rotational approach showed -1.8 J when comparing the potential energy with the mechanical work. The difference observed when

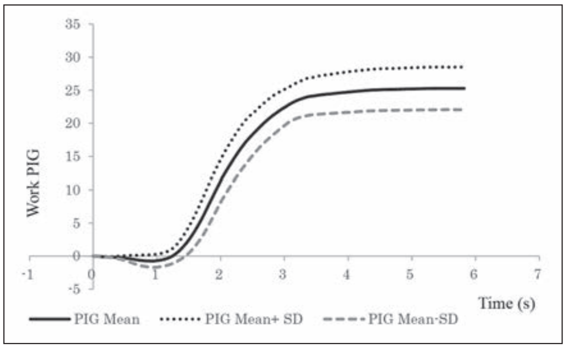

Figure 7. Mean value and SD of Work for Plug-In-Gait (PIG) for one subject.

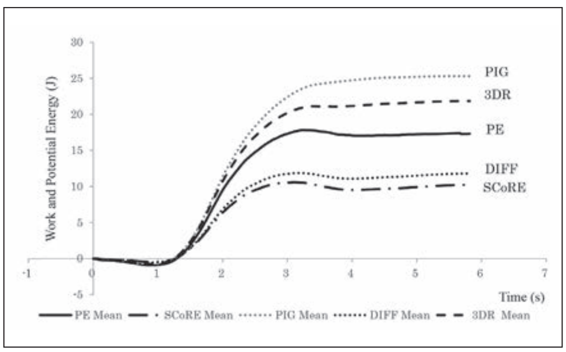

Figure 8. Difference between mean values of potential energy and lower limb work of hip motion at 40 degrees bending forward of the trials for the four methods for one subject.

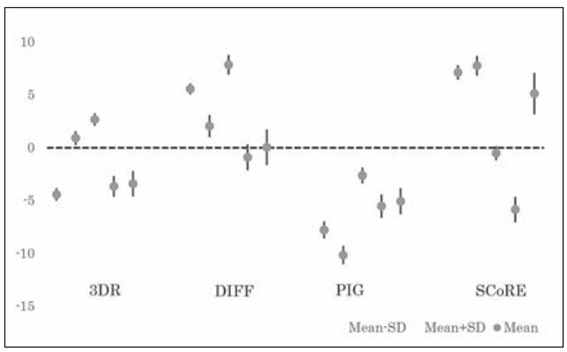

Figure 9. Results of the difference between the potential energy and mechanical work for all the five subjects for the four methods.

subtracting the potential energy from the mechanical work revealed that in the DIFF model the mechanical lower work was greater than the potential energy. It appears that the HJC was too much backward in the DIFF method because as far as the HJC is backward, the hip extension moment becomes greater. Also the PIG model showed a lesser moment when subtracting the potential energy from the mechanical work. It appears that the HJC was too much forward in the PIG method. The results observed in this study showed that 3D rotational method has less difference compared to DIFF, SCoRE and PIG method.

In this way, we could distinguish one of the HJC estimation method as the most adequate method to calculate the most accurate hip joint moment. This is the merit of our newly developed method.

The results also suggest that there are several limitations related to the comparison methods used in this study. Though techniques used in estimation of the HJC location are influenced by many factors. Attributes like marker size and the reflection capacity might also contribute to measuring error. Furthermore, joint moments were calculated from skin-based optical motion capture data.

Previous studies have found differences in kinematic and kinetic data between commonly used gait models and medical imaging based methods [20, 21]. Lenaerts et al. [21], have recommended medical imaging based methods to obtain accurate kinematic data. However due to high costs, ionizing radiation risk and long post processing time, these medical imaging based methods are not routinely used on the tester or the patients.

Using our new method, we could judge the accuracy of the hip joint location without using X-ray or magnetic resonance imaging (MRI). This might be a potential merit of our method.

The present study only processed five subjects' data for comparison, future studies using medical imaging data such as X-ray or MRI for more subjects to assess the reliability of the accuracy of the techniques for better comparison. Moreover we did not handle the knee moment and ankle moment. The future studies will analyze the knee and the ankle joints centre location reliability.

Conclusion

The inaccuracy of the estimation of the HJC location might be the main factor parameter related in error of the joint moment calculation. When the joint moments are accurate, the total work of the joints should be identical with the increase of the potential energy. Using this concept, the model in which the most accurate joint moment can be calculated was identified. However, given that these techniques are commonly used in the motion analysis laboratory set by researchers and clinicians, more investigations are needed in order to upgrade laboratory setting and joint center prediction methods.

Acknowledgments

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Conflicts of interest

None declared.

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