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Original Article

Greater trochanter location measurement using a three-dimensional motion capture system during prone hip extension

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Abstract. [Purpose] The greater trochanter (GT) is an important structure in biomedical research, but the measurement methods require development. This study presents data from a new measurement method that does not use GT-marker-based measurement (No GT-m) in comparison with GT-marker based measurement (GT-m). [Subjects and Methods] We recruited 20 healthy subjects, who were asked to perform and maintain a prone position and then move to the prone hip extension. A motion capture system collected the kinematic data and the location of the GT was calculated by two measurements. [Results] GT migration distance differed significantly between the two measurements and the coefficient of the variation value was lower for the No GT-m method. Thigh lengths of the No GT-m method were comparable to the original lengths. There were significant differences between the GT-m and the other methods. [Conclusions] These data suggest that the GT-m method yielded a lower precision with a smaller GT migration distance. In the comparison of thigh length, the No GT-m method was in close agreement with the original length. We suggest that determining the location of the GT using the No GT-m has greater accuracy than the GT-m method.

Key words: Greater trochanter measurement, Motion capture system, Prone hip extension

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INTRODUCTION

The greater trochanter (GT) is an important site for biomedical research[1, 2]. It is also an important structure, giving the attachment architecture for tendons, enhancing complex movement[3]. Furthermore, it demonstrates topographical anatomy[4] and the location of the GT is used to calculate appropriate cane length[5]. In the clinic, the location of the GT is commonly used by manual therapists for diagnoses and treatment[6]. As a bony landmark, the GT gives a reference point for the measurement of joint motion[7]. Also, recognizing the migration of the GT from the original location can facilitate identification of abnormal movement—such as femoral anterior glide syndrome—by manual therapists[8].

Despite the importance of GT within manual therapy, greater study of its measurement is required. Many previous studies of lower limbs have used computed tomography[9, 10], magnetic resonance imaging[11] or X-rays[12]. However, these methods have several disadvantages: these are not cost and time-efficient and obtaining the data requires special skills[1]; the data are obtained in the supine position and are not appropriate for motion analysis[13]; computed tomography increases the risk of exposure to radiation[14].

Three-dimensional motion capture systems do not have these disadvantages and are commonly used to analyze movement. Although the GT marker-based measurement (GT-m) system can be used to determine the location of the GT by placing a reflective marker thereon[15–18], its location according to movement using this method has not been adequately investigated.

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Also, few studies of other methods of examining GT using three-dimensional motion capture systems have been conducted.

Thus, the purpose of this study was: (1) to develop a new measurement system that does not use GT marker-based measurement (No GT-m) to calculate the location of the GT from the coordinates of the other markers, (2) to compare the GT-m and No GT-m measurements. We hypothesized that the two methods would produce significantly different results, with those of No GT-m being more accurate.

SUBJECTS AND METHODS

Twenty healthy subjects (9 males and 11 females) were enrolled. Participants were excluded if they had neurological or musculoskeletal problems within the past 12 months; had a history of surgery of the spine, pelvis or lower limbs; performed hip extension less than 15° or had discomfort during trials. Their age was 21.65 ± 1.81 years (mean, standard deviation), height 168.80 ± 7.38 cm and weight 60.95 ± 7.69 kg. Prior to the study, all participants provided written informed consent and the study procedure was approved by the Inje University Faculty of Healthy Sciences Human Ethics Committee.

Participants were in the prone position with their legs straight and their heads positioned on the midline. They were asked to perform a prone hip extension on their dominant side to 15° holding their knee extended. All individuals were considered right-leg dominant as they used their right leg to kick a ball[19]. Prior to the test, subjects were instructed on the required posture and allowed to practice for 5 min. They were asked to maintain the prone position and then perform the prone hip extension, keeping each posture for 5 sec.

An eight-camera vicon motion capture system (Oxford Metrics Group Ltd., Oxford, UK) was used to measure three-dimensional hip kinematics with a sampling rate of 100 Hz. When the subjects were prone, one reflective marker was placed on the GT and four markers were placed on their dominant upper leg to obtain the location of the GT during tasks. The coordinates of markers were captured in the middle 3 sec of a task.

To identify the location of the GT, the GT marker-based measurement (GT-m) and no GT marker-based measurement (No GT-m), were performed and compared. In the GT-m, the location of the GT was determined from the migration of the coordinates of markers that were placed during the prone position and prone hip extension. In the No GT-m method, the length from the four reflective markers (A, B, C, D) on the upper leg to one reflective marker (GT1) indicating the GT during the prone position was calculated to identify the location of the GT. The length lA between A (a, b, c) and GT1 (x, y, z) was calculated using Eq. 1:

$$(1)\quad l_A = \sqrt{(a-x)^2 + (b-y)^2 + (c-z)^2}$$

When the subjects extended their legs, the changes in the locations of the four markers on an upper leg, A'(aA', bA', cA'), B'(aB', bB', cB'), C'(aC', bC', cC') D'(aD', bD', cD'), were used to calculate the change in the coordinates of GT, GT'(x',y',z'). The distances between the four markers and GT1, lA, lB, lC, lD, respectively, are identical to the distance between the four markers and GT' during the prone hip extension because the upper leg shank is a rigid body segment. According to this, the formula of GT' is shown in Eq. 2:

$$(2)\quad \begin{array}{l} \sqrt{(a_{A'}-x')^2 + (b_{A'}-y')^2 + (c_{A'}-z')^2} = l_A \\ \sqrt{(a_{B'}-x')^2 + (b_{B'}-y')^2 + (c_{B'}-z')^2} = l_B \\ \sqrt{(a_{C'}-x')^2 + (b_{C'}-y')^2 + (c_{C'}-z')^2} = l_C \\ \sqrt{(a_{D'}-x')^2 + (b_{D'}-y')^2 + (c_{D'}-z')^2} = l_D \end{array}$$

From this, the changed location of GT, GT' can be calculated as shown in Eq. 3:

$$(3)\quad \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} -2a_{A'}+2a_{B'} & -2b_{A'}+2b_{B'} & -2c_{A'}+2c_{B'} \\ -2a_{A'}+2a_{C'} & -2b_{A'}+2b_{C'} & -2c_{A'}+2c_{C'} \\ -2a_{A'}+2a_{D'} & -2b_{A'}+2b_{D'} & -2c_{A'}+2c_{D'} \end{pmatrix}^{-1} \begin{pmatrix} l_A^2 - l_B^2 - a_{A'} - b_{A'} - c_{A'} + a_{B'} + b_{B'} + c_{B'} \\ l_A^2 - l_C^2 - a_{A'} - b_{A'} - c_{A'} + a_{C'} + b_{C'} + c_{C'} \\ l_A^2 - l_D^2 - a_{A'} - b_{A'} - c_{A'} + a_{D'} + b_{D'} + c_{D'} \end{pmatrix}$$

To compare the two measurements, the GT migration distance measured using the two methods and the length of the thigh were calculated by Eq. (1). The migration distance of the GT is the distance between GT, the location of the GT during the prone and GT', measured using the two methods during prone hip extension. The length of the thigh is the distance between the lateral epicondyle and the GT that is a palpable length[1] and it is measured during prone hip extension using the coordinates of GT measured using the two methods. Also, the original length, which is the actual length from the lateral epicondyle to the GT, was measured using a measuring tape to compare the two methods.

Data were analyzed using SPSS ver. 18.0 (SPSS, Inc., Chicago, IL, USA) to compare the two measurements using a significance threshold of $p<0.05$. The Kolmogorov-Smirnov test was used to assess the normality of the distribution of variables. The migration distance of GT was compared using the Wilcoxon test and the coefficient of variation (CV) was calculated. Bland-Altman plots[20] were used to show visual agreement and compare the measurement methods using the length of the thigh. The difference in thigh length was calculated with repeated one-way analysis of variance and Bonferroni corrections were used for specific pair-wise comparison.

Table 1. GT migration distance and thigh length

	GT migration distance		
	GT-m		No GT-m
Mean ± SD (cm)	1.09 ± 0.94		4.33 ± 0.76
CV (%)	86.24		17.55
	Thigh length		
	Original length	GT-m	No GT-m
Mean ± SD (cm)	40.33 ± 0.64	39.63 ± 0.67	40.44 ± 0.6

SD: standard deviation; CV: coefficient of variation; GT: greater trochanter; GT-m: greater trochanter marker-based measurement; No GT-m: no greater trochanter marker-based measurement

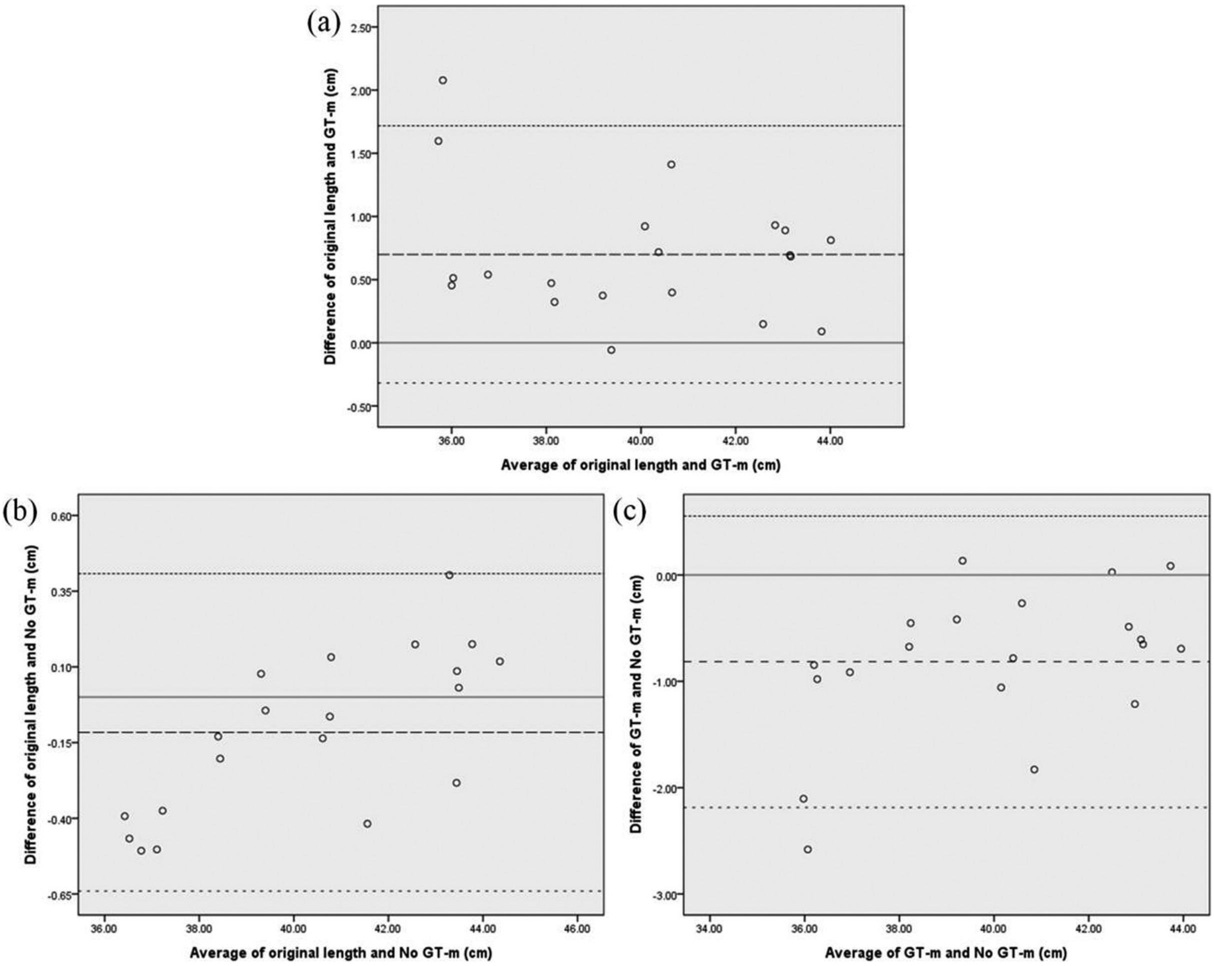

Fig. 1. Bland-Altman plots of average versus difference between (a) original length and greater trochanter marker-based measurement (GT-m), (b) original length and no greater trochanter marker-based measurement (No GT-m), (c) GT-m and No GT-m. Line; short and dashed lines: the mean ± 1.96 SD of the differences, long and dashed line: the average of the difference, gray line: zero reference line.

RESULTS

The mean values and coefficients of variation (CV) of the migration distance and leg length are shown in Table 1. The migration distance of the GT during the prone to the prone hip extension differed significantly between the two measurements ($p<0.001$), and the CV value was lower for the No GT-m. There were significant differences in leg length between the original length, GT-m and No GT-m ($F=28.163$, $p<0.001$). There was not a significant difference between the original length and No GT-m ($p=0.200$) but the GT-m was not comparable for the original length and No GT-m ($p<0.001$). The Bland-Altman plot showed that all observation pairs were in a mean ± 1.96 SD difference between original length and No GT-m (Fig. 1).

Furthermore, the limit of agreement for thigh length between the original length and the No GT-m method was lower than that when the GT-m was compared with original length and No GT-m.

DISCUSSION

In this study, we examined a non-marker-based measurement method (No GT-m) to evaluate the location of the GT. Three-dimensional motion capture systems are frequently used to analyze movement and commonly use the movement of reflective markers placed on a bony landmark[15–18]. In contrast, the No GT-m method involves calculating the coordinates of the GT from the location of four markers placed on the thigh. It is different from the conventional method, in which markers are placed directly on the part of the body that is being examined, such as GT marker-based measurement (GT-m). In the study of Hwang et al.[21], four markers were used as a reference landmark for reorientation, and other markers were reoriented according to the reference landmark. Although cephalometric landmarks were examined, several markers can be used as a reference mark for reorientation. Therefore, we obtained the changes in GT coordinates based on four reference markers during prone hip extension, following determination of marker location.

We investigated the GT migration distance and the thigh length to compare the GT-m and No GT-m measurement methods. Although the data were captured during the same movement, this study showed that the migration length of the GT using GT-m was significantly different to that using the No GT-m method. This difference might be caused by movement of soft tissue due to the GT marker being placed on the skin. The main limitation of body surface markers is due to skin deformation depending on the body movement and sites to place a marker[22, 23]. Furthermore, the displacement of the reflective marker placed on the artefacts would be incorrect in sites closer to the hip joint[24]. In the study of Moriguchi et al.[15], the GT landmark resulted in greater discrepancies when measuring the range of motion, although the findings were obtained during hip flexion.

Also, the coefficient of variation (CV) of the GT migration length was calculated to assess the accuracy of the two methods; the CV of No GT-m measurements was lower than that of the GT-m method. The migration value was similar because all subjects were healthy without any pain or difficulties[8]. Therefore, the GT-m method has greater variation and lower accuracy. The precision of the GT migration measurement is important for clinical tests and studies of the hip joint. The prevalence of hip pain varies among populations[25, 26]. Hip joint pain is likely related to accessory movements[8] that are important for a full range of motion[27]. The accessory movements of the hip joint are gliding, rolling, and spinning[28], and the qualities of the accessory movements are often related to an adequately functioning limb[29]. The anterior femoral glide syndrome suggested by Sahrmann[8] is one of the dysfunctional accessory movements of the hip joint. Anterior femoral glide syndrome can be evaluated by assessing the extent to which the GT translates to the anterior during the prone hip extension test[8] that is frequently used as a clinical tool[30, 31] and palpation of GT has the potential for error[32]. Thus, a study of GT displacement for examination of hip joint problems is warranted.

To determine which method is better, we compared the thigh lengths from the GT to the lateral epicondyle, calculated using the two methods, as the thigh is a rigid body segment. Also, the thigh length is often used as a component for femoral modeling[1]. The length using GT-m was significantly different from the original length and that determined using the No GT-m method, suggesting that the GT-m method is less accurate. Also, the No GT-m method yielded a thigh length similar to the original value; however, the value determined using the GT-m was not in agreement. Obtaining accurate body landmarks is crucial because discrepancies could lead to poor assessment of impairments and asymmetries. In this study, the No GT-m value differed from the original length because the accuracy of the three-dimensional system is 1–2 mm in the x and y axies and 4–6 mm in the z axis[33].

This study had several limitations. First, only healthy individuals were enrolled. Furthermore, the displacement of the GT was determined during prone hip extension. Therefore, further work should examine a greater range of movement and other patient groups. We also did not compare the actual location of the GT using the motion capture system. Additional study is required to evaluate whether the location of the GT using these methods is agreement with its actual location.

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