Quantitative analysis of the Trendelenburg test and invention of a modified method

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Title

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Conflict of interest statement

None

Ethical review committee statement

This investigational protocol was conducted with the approval of the Kanazawa University Graduate School of Medicine Ethics Committee. In accordance with the requirements of this review, all subjects were provided informed consent.

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Abstract

Background While the Trendelenburg test has been used for 120 years to detect hip abductor muscle weakness, the methodology has not been standardised.

Purposes This study undertook to quantitatively analyze the relation between abductor muscle activity and pelvic tilt angle in the Trendelenburg one-leg stance, examine the pitfalls associated with performing the T-test, and develop a modified method that will produce reliable results.

Methods A convenience sample of 15 healthy males was asked to assume a one-leg stance in ten different postures, five with mild flexion on the unsupported side, and five with severe flexion. Trunk sway angle, pelvic tilt angle, and the pelvic on femur (POF) angle were measured for each posture. Statistical analysis was used to assess differences in hip abductor activity and public tilt angle between the control posture and the test postures.

Results With minimum trunk sway, hip abductor muscle activity increases when the pelvis is elevated and decreases when it is dropped. With trunk sway toward the test side, abductor muscle activity decreased when the pelvis was elevated; with trunk sway toward the non-test side, muscle activity stayed approximately constant when the pelvis was dropped.

Conclusions Based on the results we developed a modified T-test methodology that would improve reliability. This test should be performed with minimum trunk sway and severe flexion on the non-test side. The assessment of muscle weakness is based on whether the patient can keep the single-leg standing posture when forced to elevate the pelvis, not simply on the pelvic drop. In future research, we will perform the modified T-test on patients with a suspected hip abductor deficiency, and assess the usefulness of the modified test.

Introduction

Weakness of the abductor muscle is the major cause of claudication resulting from diseases of the hip joint. Therefore, evaluation of hip abductor muscle strength is important in diagnosing and treating such diseases. The Trendelenburg (T) test was first reported by Friedrich Trendelenburg in 1895 as a physical examination method for detecting severe abductor muscle weakness [1]. Generally, if the patient assumes a one-leg stance and the pelvis drops on the non-test (the non-stance) side, the test result is read as positive; in other words, the abductor muscle is weak. The T-test has long been a popular method for physical examinations; however, the details and evaluation method of the procedure are usually described vaguely and have not been standardised. In 1985, Hardcastle et al [2] developed a T-test method which they called the standard Trendelenburg (sT)-test. In this method, the participant is instructed to elevate the pelvis as high as possible on the non-test side, and if sufficient elevation of the pelvis can be maintained for 30 seconds, the test result is considered negative. If insufficient elevation and drop of the pelvis occur, the test result is considered positive. This method is now used worldwide as a method for evaluating hip abductor function after total hip replacement (THR). However, its reliability does not yet clear. In daily medical practice, we often hesitate to judge that the test is positive or negative because the pelvic drop（or insufficient pelvic elevation）is not immediately obvious. Additionally, we wonder whether the hip flexion angle of non-test side and a trunk sway has an effect on the results. The aims of this study were to quantitatively analyze the relationship between abductor muscle activity and the pelvic tilt angle in the one-leg stance posture; to examine the pitfalls associated with performing the T-test; and ultimately, to invent a better method, which we call the modified Trendelenburg (mT)-test.

Materials and Methods

Participants

A convenience sample of 15 healthy men（30 hips）was recruited. Inclusion criteria were as follows: 1）older than 18 years, 2）no current or previous injury to the lumbar spine, pelvis, or lower extremities within the past 12 months, 3）no previous surgery to the lumbar spine, pelvis, or hip, 4）normal passive and active range of motion of both hips, 5）5 of 5 scores bilaterally on manual muscle testing of the hip abductor muscle. The mean age was 31.4 years（range, 22-55 years）, the mean body weight was 63.9 kg（range, 54.5-86.0 kg）, and the mean height was 171.5 cm（range, 163.2-180.7 cm).

Methods

Procedures

Participants assumed a one-leg stance in 10 different postures, as described below（Figure

1）; measurements were taken of the trunk sway angle, the pelvic tilt angle, and the pelvic-on-femur（POF） angle（Figure 2）; and the relationship between hip abductor muscle activity and the pelvic tilt angle was assessed. "Posture 1: control" was defined as a one-leg stance posture in which participants were given no instruction regarding pelvic tilt. In “Posture 2: pelvic drop” and “Posture 3: pelvic elevation” the participants were instructed to drop the pelvis, and to elevate it, respectively. In postures 1-3, the participants were instructed to minimize trunk sway, in order to eliminate any effect which the trunk sway might have on hip abductor muscle activity and pelvic tilt angle. Finally, in order to assess the effect which trunk sway has on hip abductor muscle activity and pelvic tilt angle, in "Posture 4: trunk sway toward test side" and "Posture 5: trunk sway toward non-test side" the participants were instructed to lean the trunk toward the test side and non-test side, respectively. In postures 4 and 5, the participants were given no instruction regarding pelvic tilt.

For each posture, the participants were asked to perform mild and severe flexion of the non-test side hip in order to assess the effect that the flexion angle of the non-test side hip has on hip abductor muscle activity and pelvic tilt angle. Mild flexion was defined as raising the toe of the non-stance side as high as the medial malleolus of the stance side, for approximately 30 degrees of hip flexion. Severe flexion was defined as raising the toe of the non-stance side as high as the knee of the stance side, approximately 80 degrees of hip flexion. Measurements of the one-leg stance postures and the hip abductor muscle activity were performed once, for two seconds per posture, for 10 different postures.

Measurement of the one-leg stance posture（Figure 2）

The Trunk sway angle, pelvic tilt angle, and pelvic on femur (POF) angle were measured for each posture using retroreflective markers fixed by adhesive tape. A total of six retroreflective markers were placed on the bilateral acromion processes of the scapula, the bilateral anterior superior iliac spine (ASIS), and the bilateral second metatarsal head. The postures were measured using a camera (EOS Kiss X3, canon, Japan) and two-dimensional motion analysis software (Move-tr/2D, Library, Japan). The camera was positioned 10 meters from the participants. A first photograph was taken in the bilateral-leg standing posture just after all markers were placed. If the line between two markers of the bilateral acromion processes of the scapula and/or the line between two markers of the bilateral ASIS were oblique relative to the floor, the markers were placed correctly again. We started the measurement only after ensuring these markers were placed almost horizontally to the floor. Once the participant was balanced in the one-leg stance posture, the camera shot continuously every 0.3 seconds for two seconds and the mean value of these angles over the two- second duration was calculated with the analysis software. As illustrated in Fig. 2, the pelvic tilt angle is formed by the line of the bilateral ASIS and the horizontal line. The trunk sway angle is formed by the line of the bilateral acromion processes and the horizontal line. We assigned a positive value to the pelvic elevation of the non-stance side, the trunk sway toward the stance side. The POF angle is formed by the line of the bilateral ASIS and the line connecting the ASIS and the second metatarsal head on the test side.

Measurement of hip abductor muscle activity with electromyography（EMG）

The hip abductor muscle activity in each one-leg posture were measured quantitatively by a surface EMG of the gluteus medius muscle. Surface electrodes were used in a bipolar derivation in order to record the EMG from the gluteus medius muscle, after proper skin preparation to reduce electrode input impedance to below 5kΩ. EMG data were sent to a computer (Dimension 9150, DELL, DELL Japan) via an A/D converter (AD16-64(LPCI)LA, Contec, Japan) at 1,000 Hz with 16-bit resolution. Subsequent analyses were performed using BIMUTASⅡ software (Kissei Comtec Co. Ltd.). EMG data were 40-Hz high-pass filtered in order to exclude electrocardiographic and movement artifacts, and then were full-wave rectified and integrated for two seconds, which is the same time used to measure postures with the camera. Hip abductor muscle activity was expressed as relative muscle activity of the gluteus medius muscle; relative muscle activity was assessed by the relative ratio of the activity on the EMG recording for two seconds during 100% maximal muscle force in manual muscle testing.

Statistical analysis

Statistical analysis was performed using SPSS (PASW Statistics Base v19; SPSS Inc., Chicago, Illinois). A two-sided paired t-test was used to assess the differences in hip abductor muscle activity and the pelvic tilt angle between the control posture and each of the four test postures. Data were expressed as mean and standard deviation (SD). The level of significance was set at $p < 0.05$. The study had ethical approval from XXXXX Hospital Ethical Review Board. All subjects gave their consent to participate in this study.

Results

Abductor muscle activity, the pelvic tilt angle, the trunk sway angle, and the POF angle on the stance side of each posture are shown in detail in Table 1 (for mild flexion) and Table 2 (for severe flexion). For ease of understanding, the results of the abductor muscle activity and measurement of each posture are shown as a pattern diagram in Figure 3. The relationship between abductor muscle activity and the pelvic tilt angle is shown in Figures 4 and 5. In summary, the results show that in relation to hip abductor muscle activity and pelvic tilt in the control posture and under conditions of minimal trunk sway, hip abductor muscle activity increased when the pelvis was elevated, and decreased when the pelvis was dropped compared with that in the control posture. However, with trunk sway toward the test side, hip abductor muscle activity decreased when the pelvis was elevated compared with that in the control posture; with trunk sway toward the non-test side, the hip abductor muscle activity stayed approximately constant when the pelvis was dropped. The difference in hip flexion angle did not have much influence on the relationship between abductor muscle activity and the pelvic tilt angle. Pelvises tended to be more elevated in severe hip flection postures than in mild hip flection postures.

Discussion

The common causes of claudication resulting from diseases of the hip joint are hip pain, leg length discrepancy, and weakness of the abductor muscle. Therefore, we think that orthopaedic doctors should be able to diagnose the causes of claudication in patients in just under a minute in the consultation room by performing the T-test, determining the presence or absence of pain, and checking for leg length discrepancy on a plain X-ray. The T-test is the simplest practical screening method for deciding whether or not weakness of the abductor muscle is the cause of claudication.

The T-test was developed by Friedrich Trendelenburg in 1895, even before the widespread use of radiography [1], and in the almost 120 years since then, it has become a standard physical examination method for identifying weakness in the hip abductor muscles. However, the details and evaluation method of the procedure have never been standardised.

A famous text described how to perform the classic T-test as follows: the foot on the non-test side should be lifted by flexing the knee while keeping the thigh extended so that the psoas muscle cannot elevate on that side [3]. Generally, a normal hip will be held stable; if the pelvis drops on the non-stance side during the one-leg stance posture, the test result is considered to be positive, indicating weakness of the hip on which the subject is standing. Baker et al. performed the T-test in the classic way [4], but this procedure is very likely to result in a pelvic drop on the non-test side, leading to false positive results. Because the psoas muscle of the non-stance side and abductor muscle of the stance side seem to act in coordination, it can be difficult even for normal people to elevate the pelvis on the non-stance side without hip flexion of that side.

In 1985, Hardcastle et al [2] developed a detailed methodology for the T-test, which they reported as the sT-test. In this method, the participant is instructed to elevate the pelvis as high as possible on the non-test side, and if sufficient elevation can be maintained for 30 seconds, the test result is considered negative. Pai et al. [5] used the sT-test to conduct evaluations after THR, and emphasised the significance of the method. The sT-test has also been cited in many other papers [6-10], and it is currently recognised worldwide as a standard method for the postoperative evaluation of the hip abduction function after THR. However, the validity of the sT-test has not yet been verified in quantifiable terms.

The reliability of T-test and sT-test does not yet clear. Kendall et al. [11] used ultrasonography, after causing a considerable decrease in hip abductor muscle strength by administering a superior gluteal nerve block, to evaluate the validity of the sT-test. Their results indicated that muscle weakness and pelvic drop were not correlated and they concluded that the sT-test was not useful as a method for diagnosing a decrease in hip abductor muscle strength. Other reports [12, 13] also have stated that the correlation between abductor muscle weakness and pelvic tilt is weak. Therefore, the assessment of the results in the sT-tests described in previous reports [5-10] might have depended more on the examiners' preconceptions than on actual hip abductor muscle function.

In our daily medical practice, we also have often hesitated to make a definitive judgment as to whether a particular test is positive or negative. We wanted to develop a T-test methodology that would improve its accuracy in the diagnosis of hip abductor deficiency. Therefore, we quantitatively analyzed the relationship between abductor muscle activity and the pelvic tilt angle in the one-leg stance posture, using the results of that analysis to examine the pitfalls of performing the Trendelenburg test, and to invent a better method, which we call the mT-test.

Our measurement results indicate first, that a direct correlation between the pelvic drop（or elevation） and the decrease（or the increase） of hip abductor muscle activity occurs only when there is minimal trunk sway. Therefore, we specify that the mT-test should be performed under the condition of minimal trunk sway.

Secondly, it can be stated that, in the control posture, a naturally, artless pelvic elevation occurs while standing on a single leg, even if the patient is not conscious of it. Therefore, to avoid false-negative results during the T-tests to detect pelvic drop due to abductor muscle weakness, patients incapable of achieving a sufficient pelvic elevation will also need to be included among positive cases, along with patients whose pelvis is noticeably lower than the horizontal reference line. Similarly, Hardcastle et al [2] stated that they considered patients with insufficient pelvic elevation as positive cases.

Finally, the pelvic drop is likely to occur even in the absence of abductor muscle weakness if the hip abductor muscle is not being worked fully, as the pelvic drop occurs in healthy subjects when they relax their muscles. Therefore, to avoid false-negative results, a forced elevation of the pelvis needs to be performed during the T-test. We examined methods that allow for performing that forced elevation of the pelvis. We noticed that the pelvic drop is accompanied by a lateral movement of the pelvis towards the test side (Figure 6) to maintain balance on one leg. We considered that the lateral movements of the pelvis during testing can be prevented through immobilization if the examiner places a hand on the outer side of the greater trochanter, thus forcing elevation of the pelvis. Furthermore, as noted previously, natural elevation of the pelvis might more likely be achieved through severe flexion of the hip joint on the non-test side.

From these considerations, we determined that in performing the T-test we should 1） ask patients to minimize trunk sway, 2） ask them to flex hips severely on non-test side, and 3） make our judgment based on whether or not the patient can elevate the pelvis when forced to do so, not just from the pelvic drop. Thus, we developed a modified Trendelenburg（mT） test as follows (see Figure 7).

1. The participant is instructed to adopt a standing posture with feet close together, and the examiner immobilises the participant by holding the hip outside the greater trochanter on the test side.（This is designed to prevent the greater trochanter moving outside, but the examiner must not try to push it inside.）

2. The participant is instructed to flex the hip on the non-test side and to lift that knee high, while minimizing trunk sway. If the single-leg standing posture is impossible to maintain, the test result is considered positive. （The participant will find it easier to understand an order to "flex the hip and lift the knee high" than "to flex the hip severely."）

The biggest advantage of this method is that it is not necessary to base the diagnosis on a slight pelvic tilt change, because the single-leg standing posture in itself becomes difficult when a hip abductor muscle deficiency exists.

Limitation

~~Downing ND et al. [4] and Picado CH et al. [11] evaluated hip abductor function using the T-test before and after THR and reported a significant decrease in T-test positive results. However, it is easy to get false-positive T-test readings from patients with significant hip pain, since even a patient who has normal hip abductor power in a supine position cannot~~

~~produce hip abductor power in the one-leg stance position when hip pain is severe. This is because when the patient produces hip abductor power while standing on one leg, the resultant force goes up to the hip joint [10], and hip pain becomes acute. Thus, T-test evaluations before and after THR may only indicate lessening of hip pain rather than an improvement of the hip abduction muscle deficiency. We believe that the T-test, including the mT-test, may be not useful at all for assessing hip abductor deficiency before THR and soon after THR in patients with strong hip pain.~~

This study is for young healthy males. The original subject of the mT test is patients of diseases of hip joint, for instance, osteoarthritis of the hip. However, we think that the relationship between the pelvic tilt and the abductor muscle strength is equivalent in these patients and healthy individuals, unless the patients have a severe hip contracture. From now on, We would like to evaluate the clinical relevance of the new mT test in patients of diseases of hip joint.

Conclusions

We quantitatively analyzed the relationship between abductor muscle activity and pelvic tilt angle in the Tredelenburg one-leg stance. The results of our analysis indicate that when we perform the T-test, we should 1) ask the patient to minimize trunk sway, and to flex the hip and elevate the knee high on the non-stance side, and 2) evaluate an insufficient pelvic elevation as well as a pelvic drop as positive. However, since the pelvic tilt is not often immediately obvious, we devised a better method, the mT-test, which does not require an assessment of pelvic tilt. In future research, we will perform the mT-test on patients with a suspected hip abductor deficiency, and assess the usefulness of the modified test.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

XXXXX conceived and carried out the all experiments, performed the statistical analysis, and drafted the manuscript. XXXXX and XXXXX contributed in developing the study design, collecting patients' data. XXXXX, XXXXX and XXXXX conceived of the study, and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

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Figure Legends

Figure 1: The ten one-leg stance postures

Figure 2: The measurement of the one-leg stance posture by trunk sway angle, pelvic tilt angle, and pelvic-on-femur angle

Figure 3: Pattern diagram of the one-leg stance postures with the hip abductor muscle activity of each posture

Figure 4: The relationship between pelvic tilt angle and hip abductor muscle activity with mild flexion of the hip on the non-test side

Figure 5: The relationship between pelvic tilt angle and hip abductor muscle activity with severe flexion of the hip on the non-test side

Figure 6: Pelvic outside movement accompanied by pelvic drop（a. Pattern diagram、b. Radiograph）

Figure 7: The modified Trendelenburg test (mT-test) method

Table 1: Measurement values of the one-leg stance postures and the hip abductor muscle activity of each posture with mild flexion of the hip on the non-test side

Table 2: Measurement values of the one-leg stance postures and the hip abductor muscle activity of each posture with severe flexion of the hip on the non-test side

Figure1

Figure 1

the mild flexion of the hip on non-test side

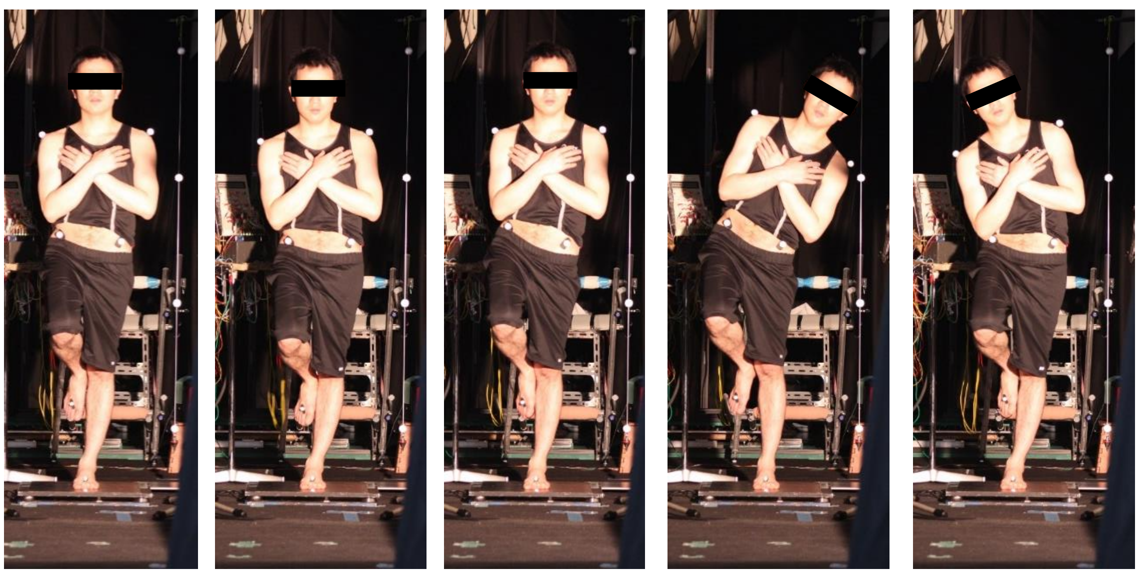
1 control

2 pelvic drop

3 pelvic elevation

4 trunk sway toward test side

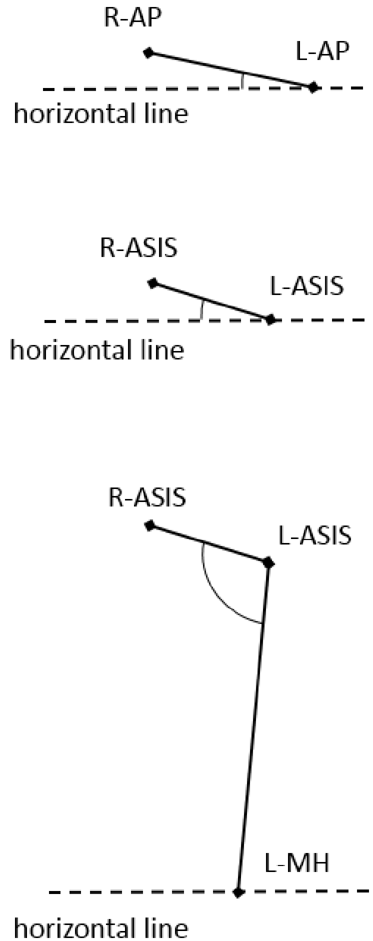
5 trunk sway toward non-test side



the severe flexion of the hip on non-test side

Figure2

Figure 2



a. the trunk sway angle
The trunk sway angle is formed by the line of the bilateral acromion processes and the horizontal line.

b. the pelvic tilt angle
The pelvic tilt angle is formed by the line of the bilateral ASIS and the horizontal line.

c. the pelvic-on-femur angle
The pelvic-on-femur angle is formed by the line of the bilateral ASIS and the line connecting the ASIS and the second metatarsal head on the stance side.

R（L）-AP: right（left） acromion processes
R（L）-ASIS: right（left） anterior superior iliac spine
L-MH: left second metatarsal head

Figure3

Figure 3

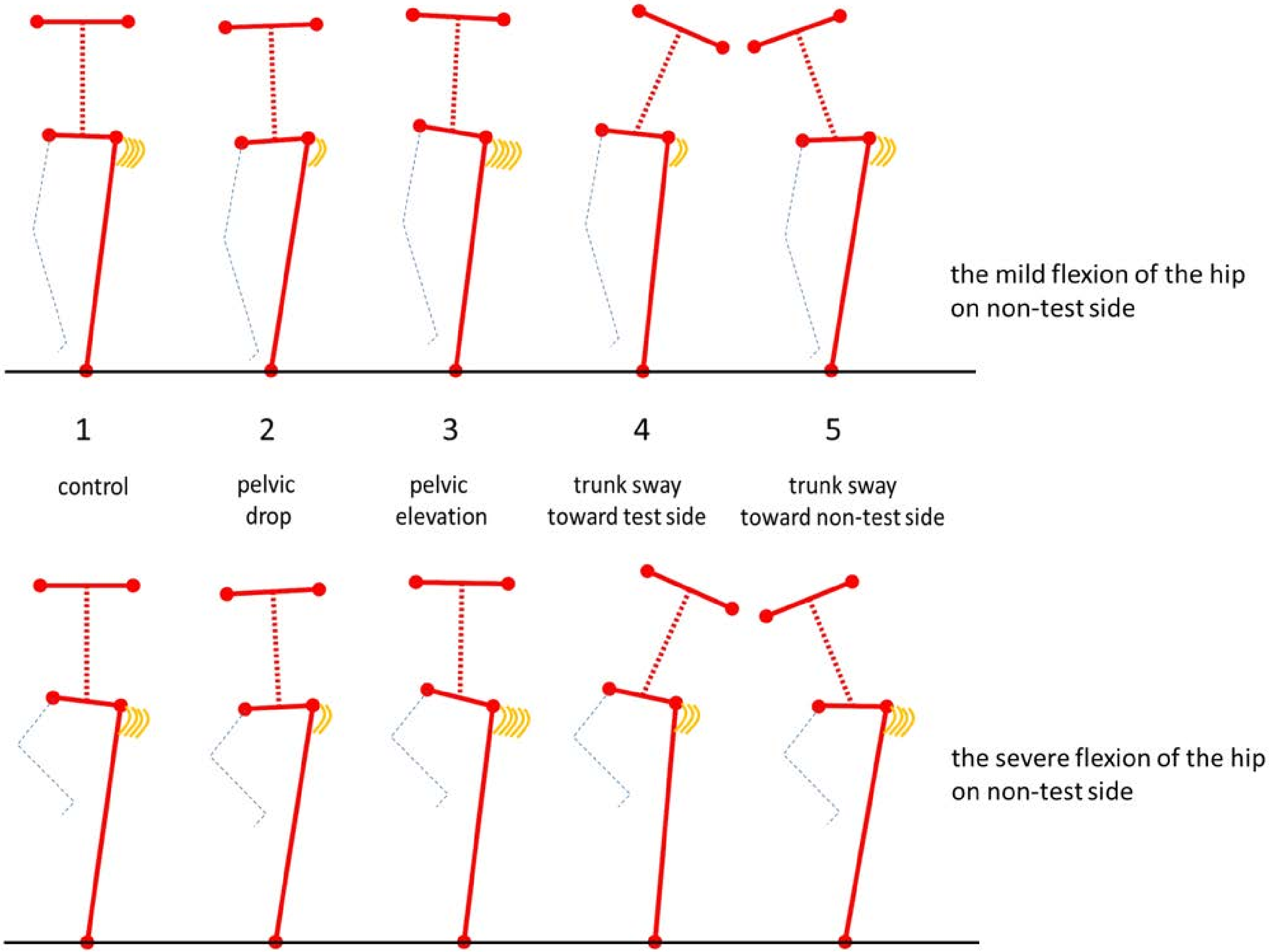


Figure4

Figure 4

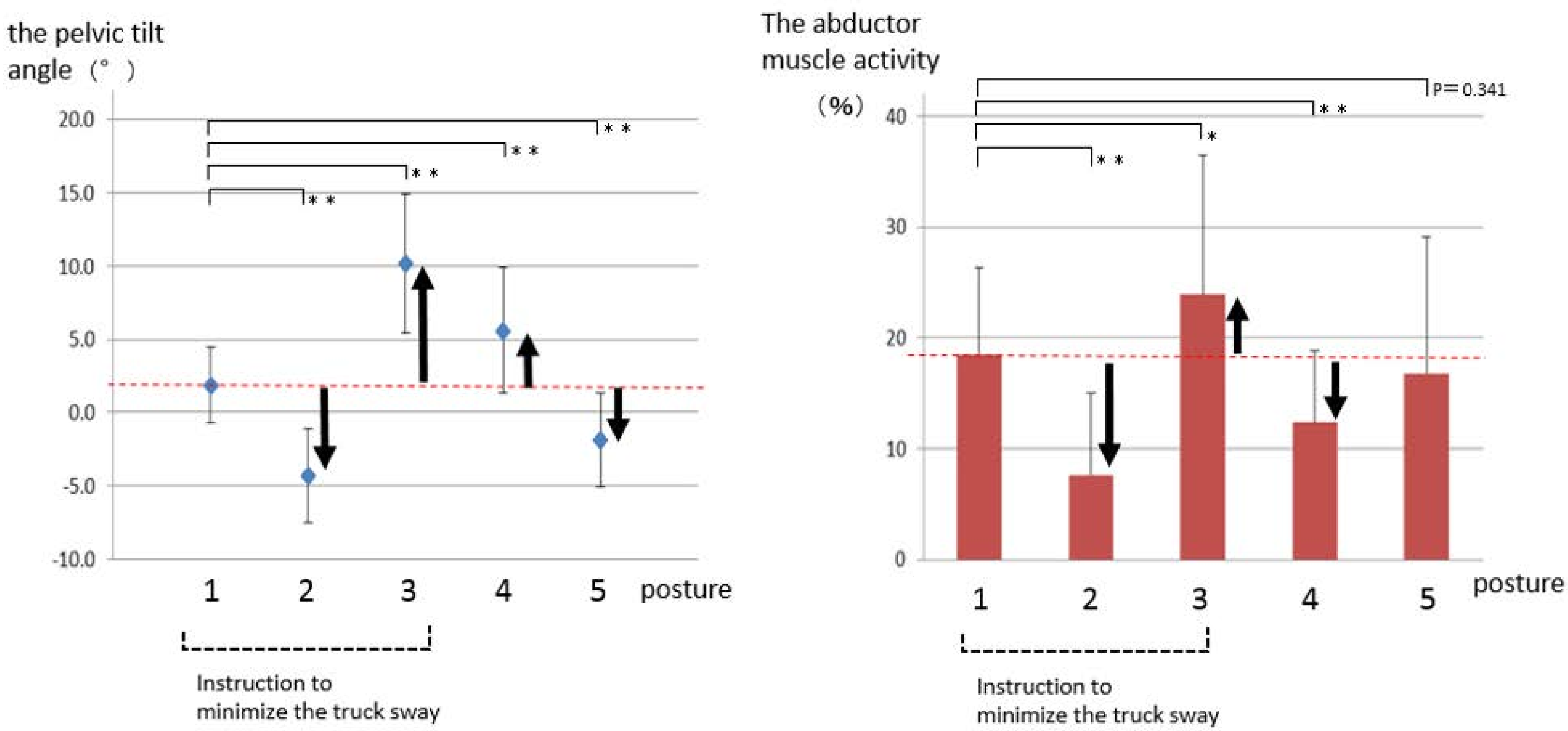


Figure5

Figure 5

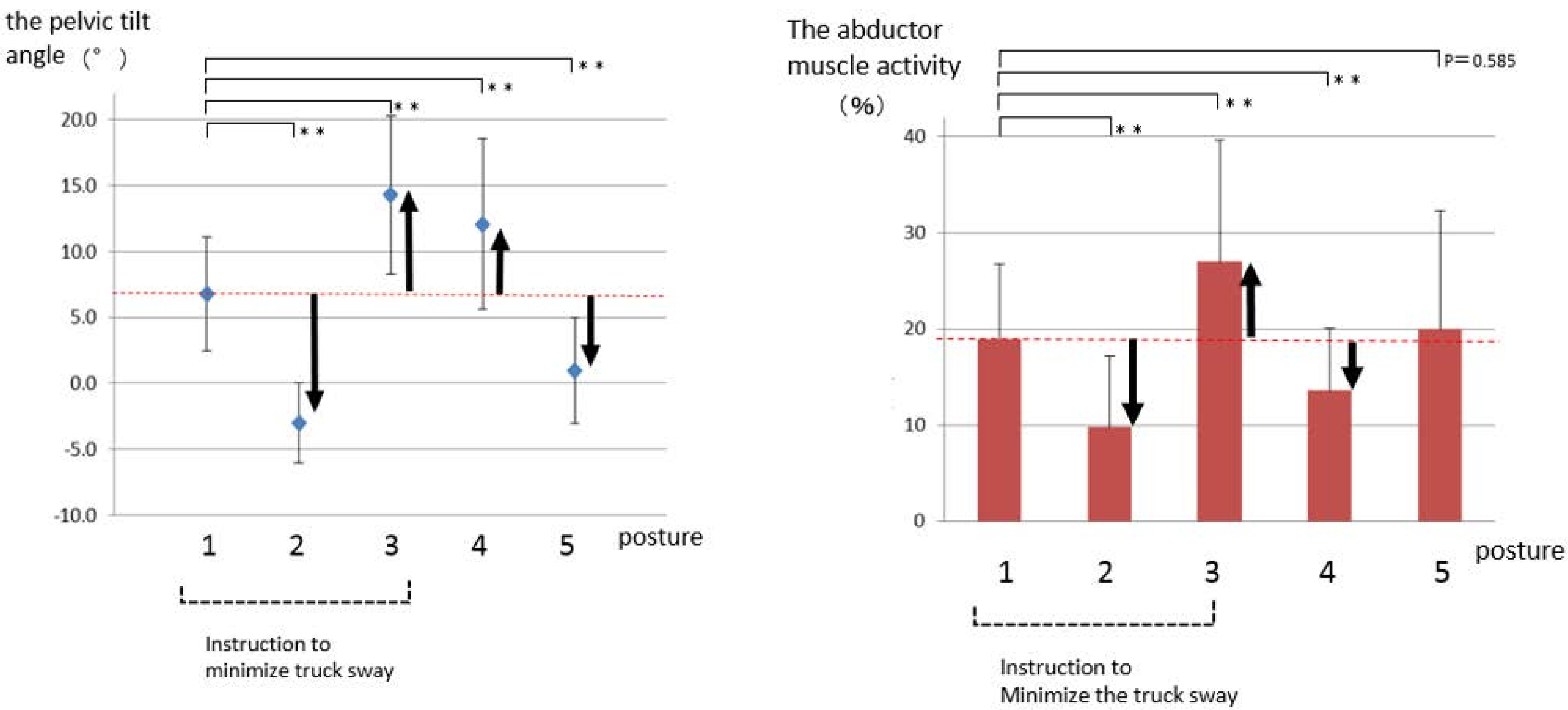
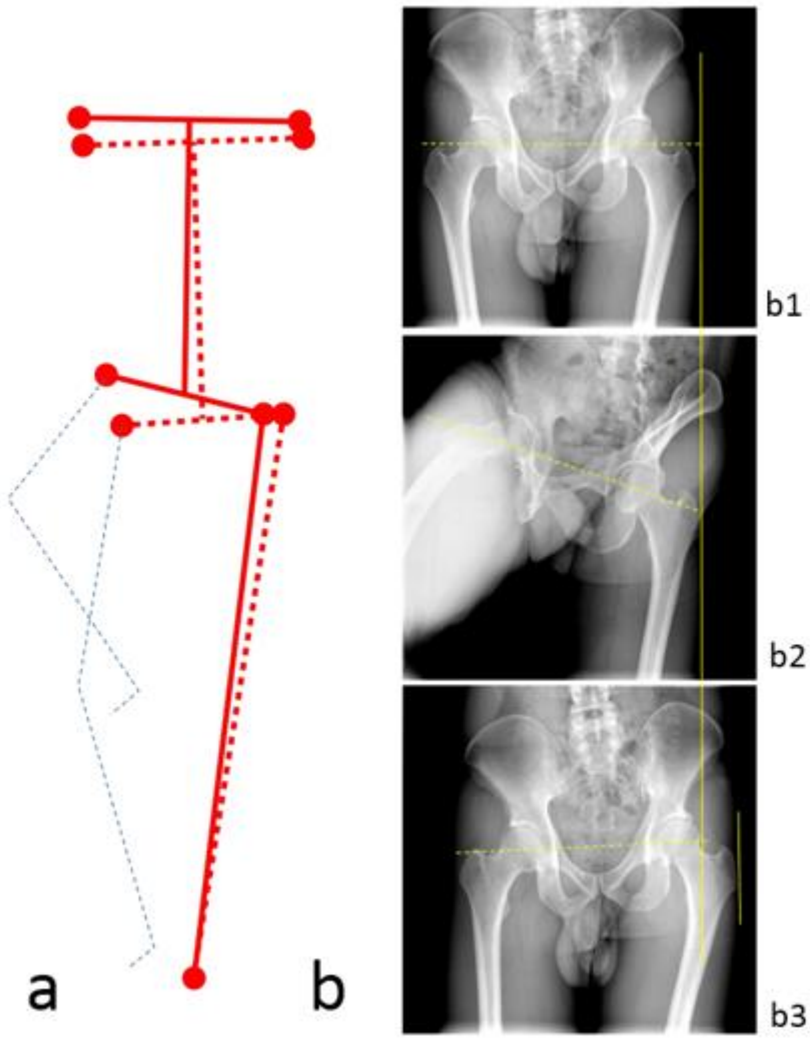


Figure6

Figure 6

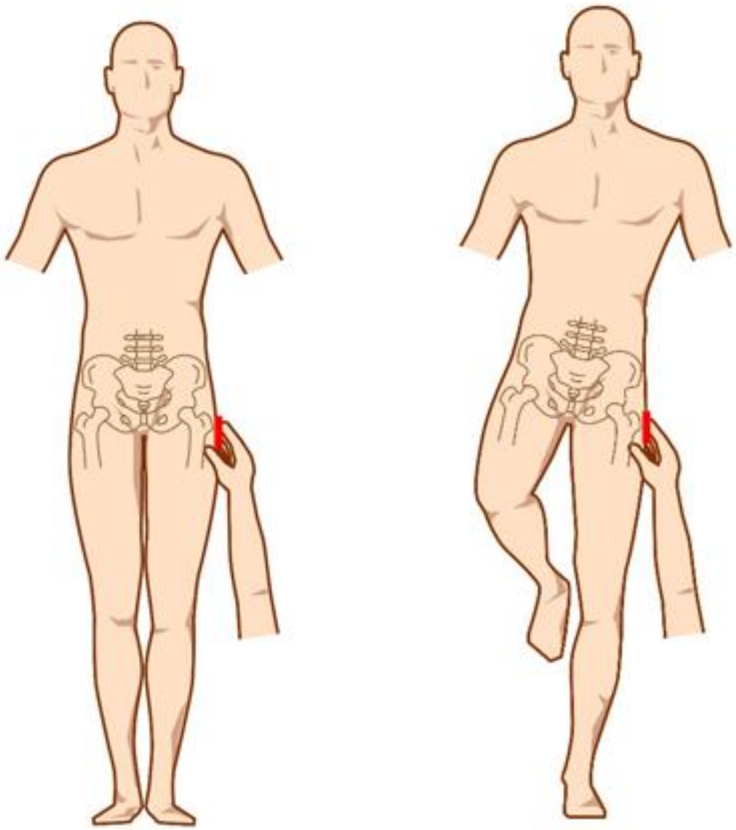


a. the comparison of the pelvic elevation posture with the severe flextion of the hip and the pelvic drop posture with the mild flextion of the hip

b. 33 year-old man. Radiographs of Bilateral leg stance posture with feet close together（b1）, and one leg stance posture of the pelvic elavation（b2） and the pelvic drop（b3）. He was instructed not to move a stance foot position.
：The greater trochanter moved outside 4.5cm in the pelvic drop posture, compared with the birateral leg stance posture and the pelvic elevation posture.
Solid lines show the lateral edge of the greater trochanter. The dashed lines connecting the bilateral femoral heads show pelvic tilt.

Figure7

Figure 7



negative

1. The participant is instructed to adopt a standing posture with feet close together, and the examiner immobilises the participant by holding the hip outside the greater trochanter on the test side.
2. The participant is instructed to flex the hip on the non-test side and to lift that knee high, while minimizing trunk sway. If the single-leg standing posture is impossible to maintain, the test result is considered positive.

Table1

Table 1 Measurement values of the one-leg stance postures and the hip abductor muscle activity of each posture with mild flexion of the hip on the non-test side

posture	1. control	2. pelvic drop	3. pelvic elevation	4. trunk sway toward test side	5. trunk sway toward non-test side
the trunk sway angle(°)	0.2±2.1	-2.1±5.3	2.6±5.7	24.2±7.3	-20.3±6.8
instruction to participants	minimize the trunk sway	minimize the trunk sway	minimize the trunk sway	lean the trunk toward the test side	lean the trunk toward the non-test side
the pelvic tilt angle(°)	1.9±2.6	-4.3±3.2	10.2±4.7	5.6±4.3	-1.9±3.2
instruction to participants	none	drop the pelvis on non-test side	elevate the pelvis on non-test side	none	none
the POF angle(°)	84.0±2.6	77.1±3.6	92.6±4.5	89.8±4.5	77.7±3.2
instruction to participants	none	none	none	none	none
Abductor muscle activity (%)	18.5±9.9	7.6±5.5	23.9±11.8	12.4±6.3	16.8±10.4

Table2

Table 2 Measurement values of the one-leg stance postures and the hip abductor muscle activity of each posture with severe flexion of the hip on the non-test side

posture	1. control	2. pelvic drop	3. pelvic elevation	4. trunk sway toward test side	5. trunk sway toward non-test side
the trunk sway angle(°)	0.4±2.5	-3.5±4.1	1.1±4.3	24.4±7.1	-21.7±7.6
instruction to participants	minimize the trunk sway	minimize the trunk sway	minimize the trunk sway	lean the trunk toward the test side	lean the trunk toward the non-test side
the pelvic tilt angle(°)	6.8±4.3	-3.0±3.0	14.3±6.0	12.1±6.5	1.0±4.0
Instruction to participants	none	drop the pelvis on non-test side	elevate the pelvis on non-test side	none	None
the POF angle(°)	89.0±4.7	78.1±3.5	96.8±6.1	96.8±7.1	80.6±4.4
instruction to participants	none	none	none	none	none
Abductor muscle activity (%)	19.0±7.8	9.8±7.4	27.0±12.6	13.6±6.5	20.0±12.3