SCIENTIFIC ARTICLE

Imaging Approaches for Accurate Determination of the Quadriceps Angle

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Objectives: A retrospective study was conducted using magnetic resonance image (MRI) and a full-length standing scanogram (FLSS) to measure the quadriceps angle (Q-angle) while avoiding soft tissue interference.

Methods: Two steps were retrospectively carried out in two case series. The first step involved using MRI to define the standardized patellar center (PC) and the tibial tubercle (TT) on the frontal plane of the MRI in one group of 60 consecutive patients (from July 2016 to December 2016, 29 men and 31 women, average of 46 years). The next step was transferring the location of the standardized PC and the TT from the MRI to the FLSS in another group of 100 consecutive patients (from April 2009 to March 2014, 50 men and 50 women, average of 36 years). The pelvis and intact femur, knee, and tibia were used to determine the Q-angle on the FLSS.

Results: The standardized PC was positioned 42% from the lateral end of femur trans-epicondylar line. The TT was 2 cm distal to the tibial articular surface and 37% from the lateral end of tibial width. The average Q-angle was 9.5° in 100 patients (8.8° in 50 men and 10.1° in 50 women, $P = 0.02$). The average femoral length was 42.9 cm in 100 patients (44.7 cm in 50 men and 41.1 cm in 50 women, $P < 0.001$). Women and men had similar pelvic width (27.9 *vs* 27.8 cm, $P = 0.89$).

Conclusion: Using the FLSS may help to accurately determine the Q-angle. Men and women have similar pelvic width. A larger Q-angle in women may be mainly due to the shorter femur.

Key words: Full-length standing scanogram; Magnetic resonance imaging; Quadriceps angle

Introduction

Patients with patellar malalignment (PM) are common in orthopaedic clinics[1]. Although PM can be caused by a large number of etiologies, the quadriceps angle (Q-angle) is believed by some to be an important contributing factor[2, 3]. The Q-angle was first arbitrarily described by Brattstroem in 1964: it is the intersecting angle of two lines, with one from the anterior superior iliac spine (ASIS) to the patellar center (PC) and the other from the PC to the tibial tubercle (TT)[4]. The Q-angle is initially measured with individuals in the supine position, with the knee extended and relaxed[5, 6]. Later, individuals are measured in standing position with the quadriceps femoris contracted[5–8]. Although both beliefs (supine or standing positions) are still debated, the measurement of the Q-angle is generally not clinically accurate. The ASIS, patella, and TT are obscure in obese individuals. Moreover, the patella can be malaligned during measurement and the Q-angle underestimated[3, 9]. Finding a better measurement technique is important.

A full-length standing scanogram (FLSS) can clearly demonstrate the ASIS, the knee, and the proximal tibia. However, the PC and TT cannot be inspected clearly. In contrast, magnetic resonance imaging (MRI) can clearly define the patella and the TT in three dimensions. By transferring the location of both anatomic landmarks from a magnetic resonance image to an FLSS, more accurate measurement of the Q-angle may be achieved. Thus, the issue about relaxing or contraction of the quadriceps femoris can be avoided.

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However, to the best of the authors' knowledge, using an FLSS for measuring Q-angles has rarely been discussed in the literature. A potentially excellent and feasible technique has, therefore, been neglected. We hypothesized that an FLSS may possibly resolve the shortcomings of clinical measurement of the Q-angle. The purpose of this retrospective study included: (i) to use MRI to assist in defining the PC and TT on the FLSS (consequently, measurement of the Q-angle on the FLSS might become more accurate and convincing); (ii) to determine the difference between clinical and imaging measurement techniques; and (iii) to investigate whether the Q-angle is different between genders and the possible reasons.

Materials and Methods

The current study consisted of two steps: the first step involved using MRI to transfer the locations of the PC and the TT on the FLSS in one group of patients; the second step involved measuring the Q-angle on the FLSS in another group of patients (Fig. 1). This study was approved by the Institutional Review Board of the authors' institution (IRB no. 201700752B0).

Localization of the Standardized Patellar Center and Tibial Tubercle on the Frontal Plane of Magnetic Resonance Imaging

From July 2016 to December 2016, 60 consecutive adult patients who had undergone knee MRI examination were included in the first study. These patients (29 men and 31 women) were aged from 28 to 68 years (average, 46 years). They underwent MRI examination for ligament or meniscus injuries without fractures or severe osteoarthritis. The inclusion criteria of the study were all patients undertaking knee MRI for injuries around the knee without fractures. The exclusion criteria were patients with abnormal gait before the injury, congenital or developmental anomalies, and metabolic or immunologic disorders.

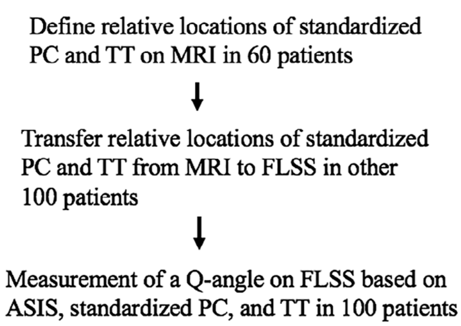

Fig. 1 The flowchart shows the measurement details. ASIS, anterior superior iliac spine; FLSS, full-length standing scanogram; MRI, magnetic resonance imaging; PC, patellar center; Q-angle, quadriceps angle; TT, tibial tubercle.

All patients were placed on the MRI examining table in the supine position without anesthesia. The foot was immobilized with a holder in the neutral position. Magnetic resonance images were obtained by the knee routine protocol using a 1.5T GE Signa HDe MRI machine (Milwaukee, WI, USA) with a dedicated knee surface coil. The knee was fully extended with the quadriceps femoris relaxed.

All transverse magnetic resonance images were referenced from a line connecting the tangent of both posterior femoral condyles (reference line) selected on scout frontal views, and this plane was also referenced to both tibial plateaus. Transverse 3-mm slices were obtained from 4 cm above the patella down to 4 cm below the tibial articular surface with at least one slice passing through the bilateral menisci and the knee joint. Frontal 4-mm slices were obtained from a plane parallel to the reference line and included the patella anteriorly. Sagittal 4-mm slices were obtained parallel to the anterior cruciate ligament with at least one slice through it.

Magnetic resonance images of all 60 patients were stored in picture achieving and communication systems (PACS) software (GE Healthcare, Waukesha, WI, USA) at the authors' institution[10, 11]. Data from around the knee were selected for analysis. Both intra-observer reliability and inter-observer reliability of data were performed by two senior authors. Each of the two authors executed measures twice, with 1-week intervals. The measures for each author were used for correlation study to acquire intra-observer agreement. The average of the twice-measured values was used to represent the definite value. The measures of the two authors were used for inter-observer study and the correlation coefficient was calculated.

The first author's measures were used in the present study.

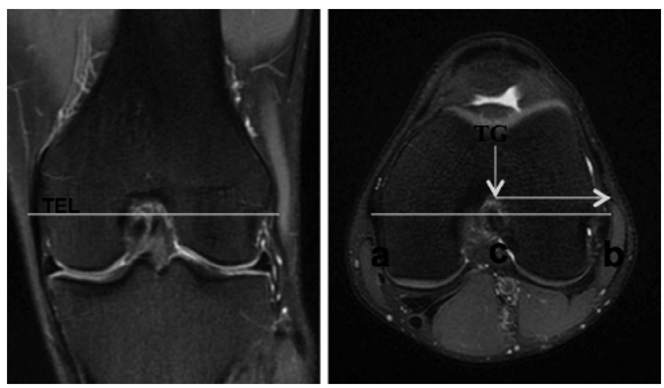

Fig. 2 A standardized patellar center (PC) is determined. Left: The femur trans-epicondylar line (TEL) is depicted on the frontal plane. Right: At the same level of the transverse plane, the deepest point of the trochlear groove (TG) is determined. A perpendicular line is drawn tangent to the posterior femur condyle. A line parallel to the posterior femur condyle tangent with the widest length is depicted (line a-b; c being the midpoint). The standardized PC is positioned at the junction of both lines and is expressed by the ratio of the distance to the lateral femur wall (dotted line) to the TEL (%).

The standardized PC was positioned along the trans-epicondylar line (TEL) of the femur on the frontal plane of the MRI (Fig. 2A). Schoettle's method was modified to position the PC[12]. On the transverse plane at the same level, the deepest point of the trochlear groove (TG) was marked. A perpendicular line from this point to the femur reference line was depicted. A line parallel to the reference line with the largest width in the femur was drawn. The PC was at the junction of both lines (Fig. 2B). The ratio of the distance from the PC to the lateral femoral wall to the TEL was measured. It was expressed as % of the TEL.

The TT was positioned at the insertion of the patellar tendon on the proximal tibia on the transverse plane of the MRI (Fig. 3A). A line bisecting the patellar tendon is depicted perpendicular to the reference line. A line parallel to the reference line with the largest width in the tibia was drawn. The junction of both lines was marked. The ratio of distance from this junction to the lateral tibial wall to the tibial width was measured. It was expressed as a percentage of the tibial width. On the frontal plane at the same level, the junction of both lines was defined by the TT. The distance from the TT to the tibial articular surface was measured (Fig. 3B).

Measurement of the Quadriceps Angle on a Full-Length Standing Scanogram

The FLSS from patients treated for chronic unilateral lower extremity injuries were used for the second study.

From April 2009 to March 2014, radiographs of the FLSS of 100 consecutive young adult patients (50 men and 50 women) were retrospectively used for this study. These patients were aged from 20 to 40 years (average, 36 years) and took an FLSS for treatment of unilateral femoral or tibial nonunions or malunions. The period from the injury to the revision surgery was an average of 1.2 years (range, 0.9–1.8 years). The number of operations per individual was between 0 and 4 (average, 2.0). Seventy-three patients required crutches or a walker for ambulation. The inclusion criteria of the study were all patients taking the FLSS for unilateral lower extremity injuries. The exclusion criteria were anomalies or old injuries in the contralateral lower extremity or pelvis, abnormal gait before the injury, and severe metabolic or immunologic disorders involving the contralateral lower extremity.

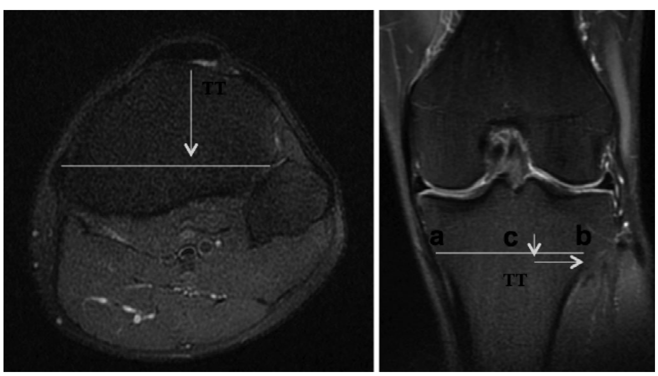

Fig. 3 The tibial tubercle (TT) is determined. Left: On the transverse plane, at the level of the patellar tendon inserted on the proximal tibia, a reference line is depicted parallel to the posterior femur condyle tangent. A line bisecting the patellar tendon is drawn perpendicular to the reference line. A lineparallel to the reference line is depicted with the largest width in the tibia. The TT is positioned at the junction of both lines and expressed by the ratio of the distance to the lateral tibial wall (dotted line) to the largest tibial width (%). Right: The tibial width line (line a-b; c being the midpoint) is depicted at the same level of the frontal plane. The distance from the line to the articular surface is measured.

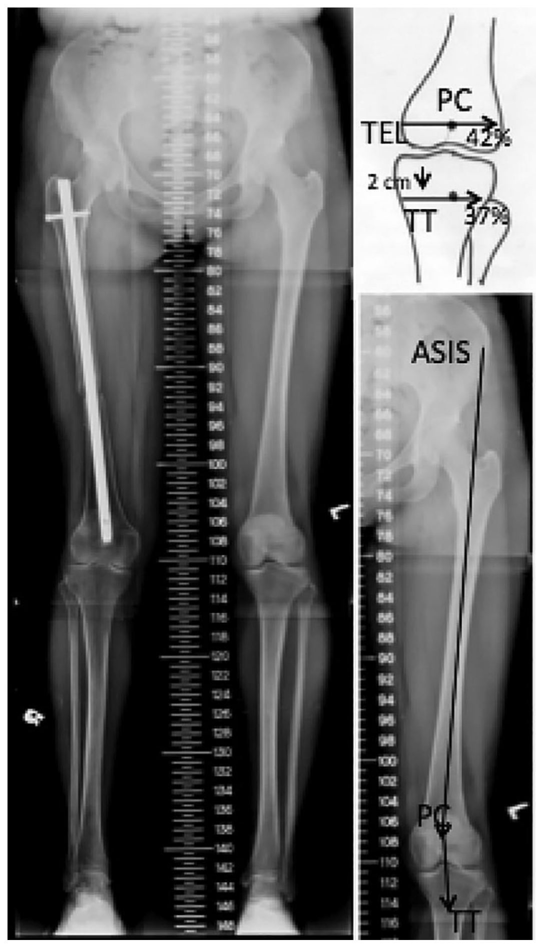

Fig. 4 The standardized patellar center (PC) is positioned on a full-length standing scanogram (FLSS): 42% from the lateral end of the trans-epicondylar line (TEL). The tibial tubercle (TT) is 2 cm distal to the tibial articular surface and 37% from the lateral end of the tibial width. The Q-angle is measured.

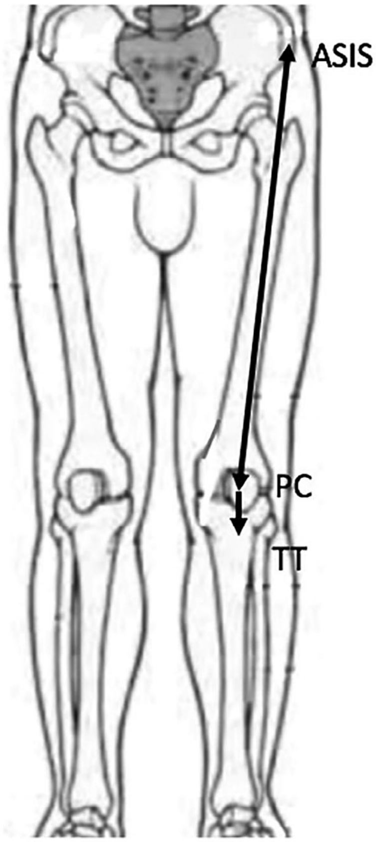

Fig. 5 The Q-angle is measured among the anterior superior iliac spine (ASIS), the standardized patellar center (PC), and the tibial tubercle (TT).

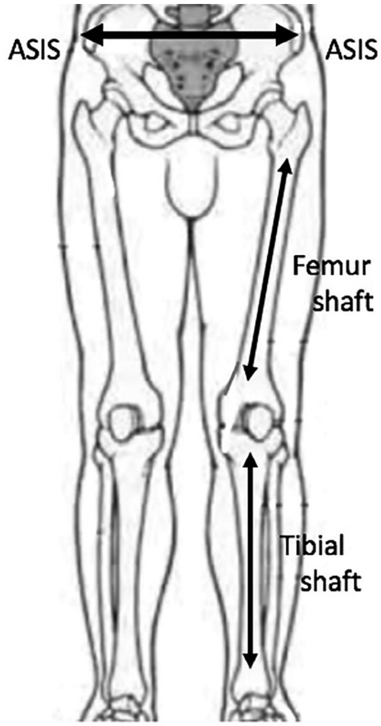

Fig. 6 Pelvic width is measured between both anterior superior iliac spine (ASIS) apexes. An anatomic angle is the intersecting angle of the femur and tibial shafts.

At the outpatient department (OPD), radiographs of local areas and the FLSS were routinely checked. All injuries were treated according to scheduled procedures. The Q-angle was measured on the FLSS after positioning of the ASIS, standardized PC, and TT (Fig. 4). The femoral length was measured from the femoral head to the intercondylar notch. Some important variations and correlations between sexes were compared statistically.

The FLSS of all 100 patients was also stored using PACS software at the authors' institution. Data from the pelvis and contralateral intact lower extremity were selected for analysis. Similarly, both intra-observer and inter-observer reliability of data were verified by two senior authors. All procedures completely followed the description in the MRI evaluation.

In the present study, the Q-angle was measured among the ASIS, the standardized PC, and the TT[5, 6] (Fig. 5). Pelvic width was measured between both ASIS apexes[1, 3] (Fig. 6). The femur length was measured from the femoral head center to the intercondylar notch[3, 7] (Fig. 7). The anatomic angle was the intersecting angle of the femur and tibial shafts[1, 11] (Fig. 6).

Statistical Analysis

Data were analyzed using Microsoft Office Excel 2010 (Microsoft Corporation, Taipei, Taiwan) software. Statistical comparison used an unpaired Student's *t*-test and $P < 0.05$ was considered statistically significant. Correlation between two samples used Pearson's product–moment correlation coefficient.

Results

Determination of the Standardized Patellar Center and Tibial Tubercle on the Frontal Plane of Magnetic Resonance Imaging

All MRI data for 60 patients could be collected and analyzed. The mean value is presented (with a 95% confidence interval). The intra-observer reliability showed correlation coefficients of 0.87 and 0.88 for each of the two authors' measures. The inter-observer reliability had a correlation coefficient of 0.82.

The standardized PC was located 42.2% (41.2%–43.1%) from the lateral end of the TEL. This value was 42.5% (41.0%–44.0%) for men and 41.9% (40.8%–43.0%) for women ($P = 0.55$).

The TT was 20.9 mm (20.2–21.6 mm) distal to the tibial articular surface. This value was 22.2 mm (21.3–23.1 mm)

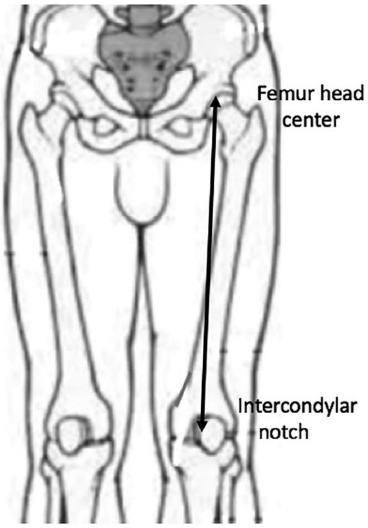

Fig. 7 The femur length is measured from the femoral head center to the intercondylar notch.

TABLE 1 Various parameters between sexes revealed on a full-length standing scanogram ($n = 100$).

Parameters	Total patients (n = 100)	Men (n = 50)	Women (n = 50)	P-value
Q-angle (∘)	9.5	8.8	10.1	0.02
Pelvic width (cm)	27.9	27.8	27.9	0.89
Femoral length (cm)	42.9	44.3	41	<0.001
Anatomic angle (∘)	5.5	5.5	5.6	0.29

Q-angle, quadriceps angle.

for men and 19.6 mm (18.6–20.6 mm) for women ($P < 0.001$).

The TT was located 37.2% (35.9%–38.5%) from the lateral end of the tibial width. This value was 37.3% (34.9%–39.7%) for men and 37.1% (35.8%–38.4%) for women ($P = 0.87$).

Measurement of the Q-angle after Positioning of the Anterior Superior Iliac Spine, Standardized Patellar Center, and Tibial Tubercle on a Full-length Standing Scanogram

The standardized PC was positioned 42% from the lateral end of the femur TEL on an FLSS. The TT was positioned 2 cm distal to the tibial articular surface and 37% from the lateral end of the tibial width (Fig. 4).

The data of all 100 patients (50 men and 50 women) could be studied completely. The mean value is presented (with a 95% confidence interval) (Table 1). The intra-observer reliability correlation coefficient was 0.85 and 0.87 for each of the two authors' measures. The inter-observer reliability correlation coefficient was 0.78.

In 100 patients, the Q-angle was 9.5° (9.2°−9.7°) (Fig. 5). The value was 8.8° (8.5°−9.1°) in 50 men and 10.1° (9.8°−10.4°) in 50 women ($P = 0.02$).

The pelvic width in 100 patients was 27.9 cm (27.7–28.1 cm) (Fig. 6). The value was 27.8 cm (27.6–28.0) cm in 50 men and 27.9 (27.7–28.1) cm in 50 women ($P = 0.89$).

The femoral length was 42.9 (42.6–43.2) cm in 100 patients (Fig. 7). The value was 44.7 (44.4–45.0) cm in 50 men and 41.1 (40.8–41.4) cm in 50 women ($P < 0.001$).

The anatomic angle in 100 patients was 5.5° (4.7° −6.3°) (Fig. 6). The value was 5.5° (4.7°−6.3°) in 50 men and 5.6° (4.9°−6.3°) in 50 women ($P = 0.29$).

The correlation between the Q-angle and the pelvic width in 100 patients was 0.004. The value was 0.10 in 50 men and −0.12 in 50 women.

The correlation between the Q-angle and the femoral length in 100 patients was −0.28. The value was −0.15 in 50 men and −0.21 in 50 women.

Discussion

The patella is highly mobile in the patellofemoral joint. The normal location of the patella in human anatomic textbooks has rarely been defined[1, 13]. Although both dynamic and static stabilizers have been described, slight quadriceps femoris contraction or a change of the lower extremity position may significantly affect the clinical measurement of the Q-angle[14]. Up to now, measurements of the Q-angle in supine or standing position, or with muscle relaxed or contracted still vary[5–8]. In addition, many patients may have a malaligned patella and the ASIS and TT can be obscure in obese individuals[3, 9]. Accurate measurement of the Q-angle is clinically unreliable. The current study avoids soft tissue disturbing factors and, therefore, may be more reliable in precisely measuring the Q-angle.

Determination of the Standardized Patellar Center and Tibial Tubercle on the Frontal Plane of Magnetic Resonance Imaging

Although the true location of the patella in the patellofemoral joint may be difficult to determine, the ideal patellar location without patellar malalignment may be defined. The current study defines the standardized PC location at the intersection of the TG and TEL[1, 6, 15, 16]. This point may fit for all available data for the patella in the normal position. Because the medial femoral epicondyle is more prominent than the lateral femorl epicondyle, the standardized PC is lateral to the midline of the femoral condyle[17, 18]. The current study found that the TG is located 42% from the lateral end of the TEL.

The TT is not located at the midline of the proximal tibial metaphysis. It is 37% from the lateral end of the tibial width and causes the patellar tendon outwards and downwards. The patellar tendon becomes the lower arm of the Q-angle and helps to provide lateral traction forces[7]. Although both the TG and TT are located lateral to the midline, the latter is more lateral[19, 20]. Therefore, the lower arm of the Q-angle forms.

Measurement of the Q-angle on a Full-length Standing Scanogram

The Q-angle is 9.5° in the current study. Women have a larger Q-angle than men, but the difference is only 1.3° (P = 0.02). Therefore, the Q-angle may not be able to be used to explain the tendency of PM in women as compared to men. Other factors, such as an imbalance of peri-patellar soft tissue tension, may be more believable. In the literature, 8°–10° Q-angles are reported in men and 15°–20° in women[2, 3, 7, 21, 22].

The Q-angle is formed by the upper arm of the quadriceps femoris and the lower arm of the patellar tendon. In the current study, men have a longer femur (44.7 *vs* 41.1 cm), a longer tibial condyle (22.2 *vs* 19.6 mm) but similar pelvic width (27.8 *vs* 27.9 cm). Therefore, a larger Q-angle in women may be mainly caused by a shorter femur, and not the wider pelvis[5, 23–25].

The correlations of the Q-angle with various other parameters in the current study are negligible (Pearson's product–moment correlation coefficient: $0.004 < r < 0.22$). This means that the Q-angle, the pelvic width, and the femoral length have no mutual connection. The comparison between various parameters must be individual. In the current study, significant difference was found between sexes in some parameters.

In the literature, the Q-angle is 8°–10° in men and 15°–20° in women. Women have a larger Q-angle, with 2.3° difference[21, 22, 26, 27]. The larger Q-angle is attributed to a wider pelvis. However, some skeptics assert that men and women have similar pelvic width[5, 23]. The 2.3° larger Q-angle may not introduce significant lateral traction forces. In these situations, all Q-angle measurements use a goniometry clinically and the accuracy of the measurement may be doubted. In 2014, Wu compared the pelvic width between sexes using plain anteroposterior pelvic radiographs[25]. Similar pelvic width was found, but women had a shorter femur, which might result in a larger Q-angle. In the current study, the Q-angle is directly measured on an FLSS. Although women have a larger Q-angle, the difference between men is only 1.3°. Therefore, the effect of the Q-angle on contributing PM may be negligible.

The anatomic angle of the femur is 5.5° in the current is study, which is consistent with reports in the literature (5°–7°)[28, 29]. Therefore, the reliability of the current study should be high.

Limitations

Possible limitations may exist in the current study. Some orthopaedists doubt the accuracy of FLSS[30]. After all, FLSS have been widely used to delegate the lower extremity alignment. It may be superior to other tools available to expose the whole lower extremity. In addition, an FLSS is taken from patients with unilateral lower extremity injuries, and not healthy individuals. Practically, persuading numerous healthy individuals to take an FLSS for a study is difficult. In the current study, all 100 patients are aged 20–40 years (average, 36 years), periods of injury of 0.9–1.8 years (average, 1.2 years). Therefore, degeneration of the hip, knee, and ankle may be neglected. Consequently, using an FLSS for measurement of lower extremity alignment may be acceptable.

Conclusion

Using the FLSS may more accurately determine the Q-angle as compared to clinical measurement. The Q-angle is an average of 9.5° in adults. Although women have a larger Q-angle compared to men, the difference is only 1.3°. Men and women have similar pelvic width. A larger Q-angle in women may be mainly due to the shorter femur.

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