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Varied influence of the femoral or tibial component on quadriceps angles: Verified by imaging studies

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ABSTRACT

Objective: The aim of this study was to evaluate the varied influence of femoral or tibial component on Quadriceps angles (Q-angle) measured with magnetic resonance image (MRI) and full-length standing scanogram (FLSS) techniques.
Methods: Two groups of patients were studied. The first group underwent MRI studies and the second group underwent FLSS studies. Two-step procedures were carried out. Knee MRI in 60 consecutive adult patients simply taken for meniscus or ligament injuries were utilized at the first step. The standardized patellar center (PC) and tibial tubercle (TT) on the frontal plane of MRI were positioned. At the second step, the FLSS in other 100 consecutive young adult patients taken for chronic unilateral lower extremity injuries were used for locating the two landmarks from MRI. The Q-angle was then determined on the anterior superior iliac spine, standardized PC, and TT on the FLSS.
Results: For 60 patients, the standardized PC was at the point 42% from the lateral end of the trans-epicondylar line of the femur. The TT was at the point 2 cm distal to the tibial articular surface and 37% from the lateral end of the tibial width. For 100 patients, the Q-angle was an average of 9.5° and 65.2% of the Q-angle was contributed by the upper arm (the femur). Women had a larger Q-angle (10.1° vs. 8.8°, $p = 0.02$) and a shorter femur (41.1 vs. 44.7 cm, $p < 0.001$).
Conclusion: The Q-angle is about 9.5° with 65.2% contributed by the femur. The Q-angle may mainly be influenced by the femoral component.
Level of evidence: Level IV, Diagnostic Study.

Introduction

Patients with patellar malalignment (PM) are common in orthopedic clinics. Although it is still controversial, the Quadriceps angle (Q-angle) is believed to be one of the important contributing factors to introduce PM, by some supporters.[1] The Q-angle was first arbitrarily assigned by Brattstroem in 1964: the intersecting angle of two lines, one is from the anterior superior iliac spine (ASIS) to the patellar center (PC) and the other is from the PC to the tibial tubercle (TT).[2] To date, there is no consensus regarding the accurate measurement of the Q-angle clinically: supine or standing, quadriceps femoris relaxed or contracted.[3] Moreover, whether the larger Q-angle in women is due to a wider pelvis or other causes is also debated.[4] A more convincing method for measurement of the Q-angle is therefore necessary.

The patellar stability in the trochlear groove (TG) is generally low.[5] Three groups of factors are attributed to affect the patellar stability in the TG: peri-patellar soft tissue tension, lower extremity alignment, and bony anomalies.[6] Clinically, imbalanced peri-patellar soft tissue tension is believed to be the most common contributing factor.[7] The upper (the quadriceps femoris) and lower arms (the patellar tendon) of the Q-angle can provide lateral traction forces. However, the influence of the two components has been investigated in few studies. Because the accuracy of clinical measurement of the Q-angle is doubted, a technique without soft tissue interference may be more feasible. In 1978, Goutallier et al first reported the effect of lateralized TT on PM.[8] In 1994, Dejour et al

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used computed tomography (CT) to define the TT–TG distance.[9] Anatomically, the TT–TG distance can affect the orientation of the patellar tendon and consequently change the Q-angle. In 2006, Schoettle et al declared that either CT or magnetic resonance images (MRIs) were effective in measuring the TT–TG distance.[10] However, the Q-angle cannot be determined with either technique due to inability to concomitantly expose all the required anatomic landmarks. A full-length standing scanogram (FLSS) can manifest the whole lower extremity but the PC and TT cannot be inspected clearly. Theoretically, all involved anatomic landmarks may be accurately defined with combined images. The influence of femoral and tibial components on the Q-angle may be comprehensively clarified. The purpose of the present study was to retrospectively use MRI and the FLSS for analyzing the components of the Q-angle. Consequently, the influence of each component might be distinguished.

Materials and methods

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

From July 2016 to December 2016, 60 consecutive adult patients who underwent knee MRI were included in the first study. The mean age of these patients (29 men and 31 women) was 46 years (range, 28–68 years). They underwent MRI examination for ligament or meniscus injury without fractures or severe osteoarthritis.

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. The MRI was obtained by the knee routine protocol using a 1.5-T 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 MRIs 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 4 cm above the patella to 4 cm below the tibial articular surface with at least one slice passing through the bilateral menisci and 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.

The MRI scans of all 60 patients were stored in picture achieving and communication systems (PACS) software (GE Healthcare, Waukesha, WI, USA) at the authors' institution.[11] Data around the knee were selected for analysis.

The standardized PC was positioned along the trans-epicondylar line (TEL) of the femur on the frontal plane of the MRI (Fig. 1, left). The Schoettle method was modified to position the PC.[10] The deepest point of the TG was marked on the transverse plane at the same level. A perpendicular line from this point to the femur reference line was shown. 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. 1, right). The ratio of distance from the PC to the lateral femoral wall to the TEL was measured. It was expressed by % of the TEL.

The TT was positioned at the insertion of the patellar tendon on the proximal tibia on the transverse plane of MRI (Fig. 2, left). A line bisecting the patellar tendon was 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 by % of the tibial width. The junction of both lines was defined as the TT on the frontal plane at the same level. The distance from the TT to the tibial articular surface was measured (Fig. 2, right).

The FLSS from patients treated for chronic unilateral lower extremity injuries was selected for the present study.

From April 2009 to March 2014, the FLSS in 100 consecutive young adult patients (50 men and 50 women) was used for this study. These patients were 20–40 years of age (mean, 36 years) and underwent FLSS for treatment of unilateral femoral or tibial nonunions or malunions. The mean period from the injury to the revision surgery was 1.2 years (range, 0.9–1.8 years). The operation numbers were 0–4 (mean, 2.0). Seventy-three patients required the use of crutches or walker for ambulation.

At the outpatient department (OPD), radiographs of local areas and FLSS were routinely checked. All injuries were treated based on scheduled procedures. The Q-angle was measured on the FLSS after localization of the ASIS, standardized PC, and TT. The TT–TG distance was measured on the FLSS by the distance of the TT to the midline subtracting the distance of the TG to the midline. A line connecting the midpoints of the TEL and tibial width was depicted. Consequently, a line parallel to the line connecting the two midpoints at the TG was drawn. The intersecting angle of the upper arm of the Q-angle and the new line represented the femoral component of the Q-angle. The Q-angle was therefore divided into two components: the femoral and tibial components on the lateral and medial sides, respectively (Fig. 3).

The FLSS of all 100 patients was also stored in the PACS software at the authors' institution. Data from the pelvis and contralateral intact lower extremity were selected for analysis.

Statistical methods

Data were analyzed using Microsoft Office Excel 2010 (Microsoft Corporation, Taipei, Taiwan) software. Statistical comparison used an unpaired Student t-test, and $p < 0.05$ was considered statistically significant. The Person product–moment correlation coefficient was used to study the correlation between two samples.

Results

All MRI data of 60 patients could be collected and analyzed. The value was indicated as mean (95% confidence interval).

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

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) and 19.6 mm (18.6–20.6 mm) for men and women, respectively ($p < 0.001$).

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

The standardized PC was defined at a point 42% from the lateral end of the femur TEL. The TT was defined at a point 2 cm distal to the tibial articular surface and 37% from the lateral end of the tibial width (Fig. 3).

The data of all 100 patients (50 men and 50 women) could be studied completely. The value was indicated as the mean (95% confidence interval) (Table 1).

The Q-angle in 100 patients was 9.5° (9.2°–9.7°). The value was 8.8° (8.5°–9.1°) in 50 men and 10.1° (9.8°–10.4°) in 50 women ($p = 0.02$).

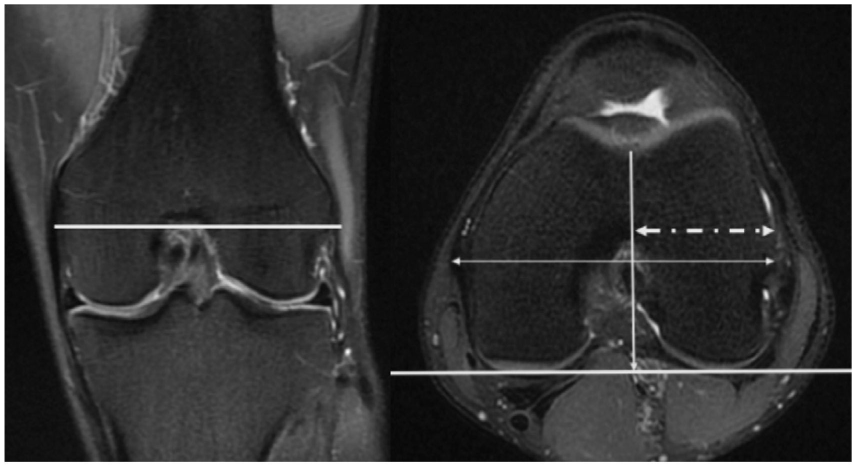
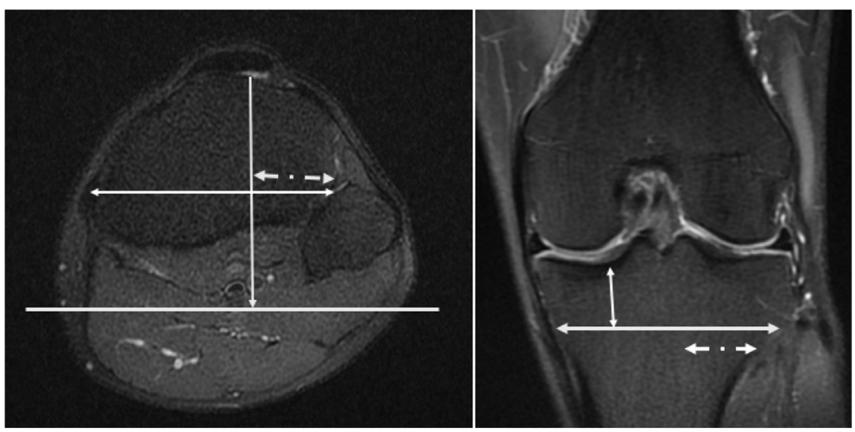


Fig. 1. A standardized patellar center (PC) is determined. (Left) The femur trans-epicondylar line (TEL) is depicted on the frontal plane. (Right) At the same level of the transverse plane, the deepest point of the trochlear groove (TG) is determined. A perpendicular line is drawn to the tangent of posterior femur condyle. A line parallel to the posterior femur condyle tangent with the widest length is depicted. The standardized PC is positioned at the junction of both lines and expressed by the ratio of the distance to the lateral femur wall (dotted line) to the TEL (%).



Fig, 2. 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 with parallel to the posterior femur condyle tangent. A line bisecting the patellar tendon is drawn with perpendicular to the reference line. A line parallel 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) At the same level of the frontal plane, the tibial width line is depicted. The distance from the line to the articular surface is measured.

The femoral component of the Q-angle in 100 patients was 65.2% (63.6%–66.8%). The value was 63.1% (60.9%–65.3%) in 50 men and 67.3% (65.1%–69.5%) in 50 women ($p = 0.18$).

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

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

The TT–TG distance in 100 patients was 0.97 cm (0.90–1.04 cm). The value was 1.20 cm (1.13–1.27 cm) in 50 men and 0.75 cm (0.70–0.80 cm) in 50 women ($p < 0.001$).

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

The correlation between the Q-angle and TT–TG distance in 100 patients was 0.04. The value was 0.22 in 50 men and 0.004 in 50 women.

Discussion

Despite that the effect of the Q-angle on PM may be doubted by a number of skeptics, theoretically the Q-angle may provide more or less lateral traction forces for the patella.[12] For those individuals with severe genu valgum, the large Q-angle may introduce lateral patellar subluxation.[13] To correct severe valgus deformity of the knee, the present study suggests that correction of valgus knee deformity from the femur may have double effects as that from the tibia.[13]

The stability of the patella within the TG is generally low. Slight contraction of the quadriceps femoris or movement of the lower extremity can pull the patella out of the TG.[5,14] Therefore, clinical measurement of the Q-angle is always debated.[3] The optimal posture of measurement for the individual still cannot achieve consensus. The evaluation of the Q-angle under a mal-aligned patella may be underestimated.[1] Moreover, the anatomic landmarks for the Q-angle (the ASIS, patella, and TT) in obese individuals are obscure and difficult to be palpated. The measurement of the Q-angle without soft tissue interference should be more valid and reliable. The present study uses the MRI and FLSS, which can avoid soft tissue factors, and therefore may be more accurate and believable.

Although it is still difficult to be proven, an ideal patellar location may theoretically be at the junction of the TEL and TG.[15,16] This position is also reasonable to be regarded as the standardized PC. Consequently, determination of the Q-angle may be more

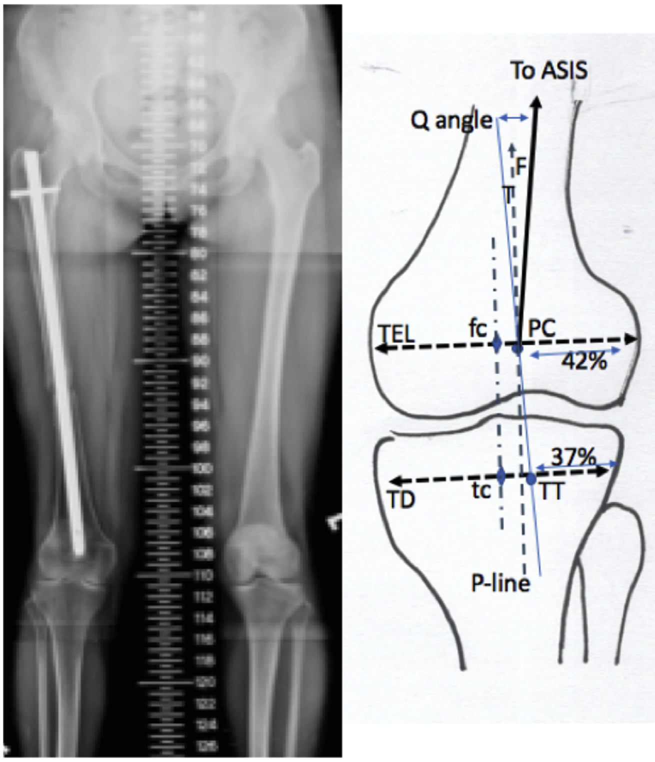


Fig. 3. Anatomic landmarks are shown: ASIS, anterior superior iliac spine; F, femoral component; fc, femoral center; MCL, midpoint connecting line; PC, patellar center; P-line, parallel line to fc–tc line; T, tibial component; tc, tibial center; TD, tibial diameter; TEL, trans-epicondylar line; TT, tibial tubercle.

convincing. The patella may have various anatomic variations, and its center may be erroneously represented by the junction of both arms of the Q-angle.[17] The present study may prevent this fault.

In the present study, the TG and TT are found to be not at the midline of the knee on the MRI and FLSS. Both structures are lateral to the midline of the knee, and the TT is even more lateral. Such characteristics introduce the TT locating inferiorly and laterally to the TG. Although women have the larger Q-angle (10.1° vs. 8.8°), men have a larger TT–TG distance (1.2 vs. 0.75 cm). The correlation between the Q-angle and the TT–TG distance is low (r = 0.04). This finding may indirectly verify that the upper arm has a greater effect compared with the lower arm. The present study further found that the femur component has provided the double effects on the Q-angle (65% vs. 35%). In other words, the femur component may mainly influence the Q-angle.

Traditionally, the TT–TG distance is evaluated by CT.[10] Recently, MRI is increasingly used, and both devices are considered with a similar effect.[10] Several studies have used either device to investigate the TT–TG distance in individuals with or without PM. The majority of these studies had supported the viewpoints that patients with PM have the larger TT–TG distance (Table 2). In patients with PM, the TT–TG distance is 13.4–19.3 mm and 12.1–15.8 mm on CT and MRI, respectively.[8,18–24] In individuals without PM, the TT–TG distance is 12.3–15.6 mm and 7.5–10.4 mm on CT and MRI, respectively.[8,18–24] All the CT values are quite larger than the MRI values. Thompson et al reported the normal TT–TG distance of 0.9–1.3 cm in CT study and similarly the CT value was slightly larger than the MRI value.[25] In the present study, the TT–TG distance was evaluated with FLSS, and 0.97 cm was achieved. The variations may be due to evaluation at different levels of the TG to define the PC: at the first craniocaudal image of cartilaginous trochlea or the TEL.[10] In the literature, the TT–TG distance may be similar between sexes.[21,22] However, in the present study men had a significantly larger TT–TG distance (1.20 vs. 0.75 cm, $p < 0.001$).[18]

Beyond 2 cm of TT–TG distance can effectively enlarge the Q-angle, and operative correction is recommended.[9,26] Clinically, patients with the over-sized TT–TG distance are uncommon. Theoretically, once it introduces PM, conservative treatment may be less effective.[9] Traditionally, the recommended correcting procedure is medial transfer of the TT (Elmslie–Trillat or Fulkerson osteotomy).[27]

With clinical measurement, the normal Q-angle is reported at 8°–10° and 15°–20° in men and women, respectively.[28] More than 15° or 20° in men and women, respectively, is considered abnormal, and PM may occur. Because patients with PM are common, the value from clinical measurement should be smaller.[1] However, in the present study, the Q-angle is even smaller compared with published articles (9.5° vs. 13°). The most possible cause may be difficult to evaluate obscure anatomic landmarks on various individuals clinically. The present study using bony landmarks may avoid these contradictions.

Table 2
The average TT–TH distance (mm) revealed on CT and MRI.

Examination device	Total individuals	Men	Women	Note
CT				
Cooney (2012)	17.2	20.1	13.7	PM
	14.8	17.6	13.5	Non-PM
Caplan (2014)	16.9	–	–	PM
	15.6	–	–	Non-PM
Tensho (2015)	19.3	–	–	PM
	14.4	–	–	Non-PM
Dickschas (2016)	13.4	–	–	PM
	12.3	–	–	Non-PM
MRI				
Dickens (2014)	12.1	13.2	11.2	PM
	8.5	8.5	8.6	Non-PM
Hingelbaum (2014)	13.5	13.4	13.6	PM
	7.5	7.5	7.6	Non-PM
Dornacher (2016)	15.8	–	–	PM
	10.4	–	–	Non-PM
Carlson (2017)	13.6	–	–	PM
	10.3	–	–	Non-PM

CT: computed tomography; MRI: magnetic resonance image; PM: patellar malalignment; TT–TG: tibial tubercle–trochlear groove; –: unavailable.

Table 1
Various parameters between sexes revealed on a full-length standing scanogram.

Parameters	Total patients (n = 100)	Men (n = 50)	Women (n = 50)	*p* value
Q-angle (°)	9.5	8.8	10.1	0.02
Femoral component of Q-angle (%)	65.2	63.1	67.3	0.18
Pelvic width (cm)	27.9	27.8	27.9	0.89
Femoral length (cm)	42.9	44.3	41.1	<0.001
TT–TG distance (cm)	0.97	1.20	0.75	<0.001

Q-angle: quadriceps angle; TT–TG: tibial tubercle–trochlear groove.

Traditionally, women with the larger Q-angle are considered to have a wider pelvis.[29] However, in clinical or radiographic measurement by some orthopedists, a similar pelvic width is advocated.[4] Furthermore, the larger Q-angle is due to the shorter femur with a similar pelvic width. A wider pelvic width is attributed to visual misidentification. In the present study, women have a shorter femur (41.1 vs. 44.7 cm) but similar pelvic width (27.9 vs. 27.8 cm) compared with men. The correlation between the Q-angle and the femoral length is low ($r = -0.28$).

The limitations of the present study may include that MRI or FLSS was acquired from patients taken for various injuries, and not from healthy persons. Practically, persuading a large number of healthy persons undergoing MRI or FLSS for the pure study is very difficult. In the present study, patients taking MRI examination are due to intraarticular soft tissue injuries within the knee. There are no fractures or severe osteoarthritis with the knee, and therefore, bony structures and alignment may be acceptable for study. Patients undergoing FLSS were 20–40 years (mean, 36 years). There are no congenital or developmental anomalies. The pelvis and contralateral lower extremity are intact. Data of measurement may be reliable. A second limitation of the present study is using the FLSS to evaluate the Q-angle. Although some skeptics doubted the accuracy of a FLSS,[30] after all this method had been widely used to represent the lower extremity alignment (including total knee arthroplasty and osteotomy). Currently, FLSS may be the most practical and reliable tool to evaluate the lower extremity alignment. The third limitation is that MRI and the FLSS are not collected from the same patient. Therefore, MRI and FLSS cannot be compared mutually. Clinically, patients receiving imaging study must follow condition needs. Unnecessary examinations are generally illegal and unethical. For studies using two devices concomitantly, a thoroughly prospective plan must be applied first.

In conclusion, the relatively accurate Q-angle may be measured by combined MRI and FLSS techniques. The Q-angle is approximately 9.5° with 65.2% provided by the femur. The Q-angle may mainly be contributed by the femoral component. Women with the larger Q-angle may be due to a shorter femur with similar pelvic width compared with men.

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