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Effects of quadriceps angle on patellofemoral contact pressure

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The authors have no conflicts of interest to
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ABSTRACT

Background: An inappropriate Q angle may affect the biomechanics of the canine
patellofemoral joint.
Objectives: The purpose of this study was to evaluate the effects of changes in quadriceps
angle (Q angle) on patellofemoral joint pressure distribution in dogs.
Methods: Eight stifles were positioned at 45, 60, 75, 90, 105, and 120° of flexion *in vitro*,
and 30% body weight was applied through the quadriceps. Patellofemoral contact pressure
distribution was mapped and quantified using pressure-sensitive film. For the pressure area,
mean pressure, peak pressure, medial peak pressure, and lateral peak pressure, differences
between groups according to conditions for changing the Q angle were statistically compared.
Results: Increases of 10° of the Q angle result in increases in the pressure area ($P = 0.04$),
mean pressure ($P = 0.003$), peak pressure, and medial peak pressure ($P ≤ 0.01$). Increasing
the Q angle by 20° increases the pressure area ($P = 0.021$), mean pressure ($P ≤ 0.001$), peak
pressure ($P ≤ 0.01$), and medial peak pressure ($P ≤ 0.01$) significantly, and shows higher mean
($P ≤ 0.001$) and peak pressures than increasing by 10°. Decreasing the Q angle increases the
mean pressure ($P = 0.013$), peak pressure, and lateral peak pressure ($P ≤ 0.001$).
Conclusions: Both increases and decreases in the Q angle were associated with increased
peak patellofemoral pressure, which could contribute to the overloading of the cartilage.
Therefore, the abnormal Q angle should be corrected to the physiologically normal value
during patellar luxation repair and overcorrection should be avoided.

Keywords: Patellofemoral pressure; patellar luxation; quadriceps angle; dogs

INTRODUCTION

The patellofemoral joint is a diarthrodial joint comprising the posterior surface of the
patella and the trochlear surface of the distal anterior femur. The patella has an important
biomechanical role in promoting efficiency by extending the leverage of the extensor
mechanism of the quadriceps muscle [1]. Patellar luxation is one of the most common
orthopedic diseases with an incidence of 15.9 cases per 1,000 patients in dogs [2]. Even
though the underlying causes are yet to be identified, coxa vara and decreased anteversion
are well known significant risk factors for various bony and soft-tissue deformities and a
resultant shifting of the axis of the force of the quadriceps muscle [3].

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The quadriceps angle (Q angle), which is formed between the long axis of the rectus femoris muscle and the patellar ligament, is considered an important parameter which shows the biomechanical effect of the quadriceps muscle on the stifle joint [4]. The Q angle in a normal dog is about 10 degrees, which increases as patellar luxation stage advances [4]. An increase or decrease in the Q angle is known to induce abnormal joint mechanics and the instability of the patella, bringing about damage to the cartilage [5]. Although it is not yet proven, an inappropriate Q angle may affect the biomechanics of the canine patellofemoral joint.

The purpose of the study was to investigate changes in patellofemoral joint pressure at different Q angles of the stifle joint harvested from canine cadavers.

MATERIALS AND METHODS

Specimen preparation

Frozen stifle joints harvested from cadavers that were euthanized for reasons unrelated to this study were utilized for this experiment. Eight legs of six beagles were disarticulated from the coxofemoral and tibiotarsal joints, wrapped in towels soaked in saline, sealed in plastic bags, and stored in a deep freezer at −80°C. Cartilage and bone were examined by visual inspection, orthopedic examination and radiographic and computed tomography image examination to identify the arrangement and shapes of bones, and any changes in cartilage and bones. Joints with any evidence of trauma or surgery, patellar luxation, shallow trochlea, medial displacement of the tibial tuberosity, patella alta, or patella baja were excluded from the experiment. Specimens that showed dislocation of the patella as a result of changes made in the Q angle during the experiment was also excluded and the associated data were eliminated. The specimens were defrosted at room temperature for 24 h before the experiment. All the soft tissues, except for the articular capsule of the joint, retinaculum, ligaments, and attachment of quadriceps muscle tendon were removed [6]. The quadriceps tendon was cut at about 2 cm from the patella. Stainless-steel beads of 1 mm in diameter were used as reference markers and embedded into a hole drilled 2 mm above the medial and lateral trochlear ridges of the distal femur with a depth of 1 mm. During the experiment, saline was continuously sprayed to prevent the tissue from drying.

Testing apparatus

The test frame fabricated for the experiment consisted of two acrylic plates connected with a hinge, a fixture to control the stifle location, a frame to exert a load on the quadriceps, and a protractor to calculate the stifle angle [7]. The femur was fastened to the plate with its long axis parallel to the plate using 2.2 mm threaded pins to prevent bending, rotating or rocking movements while the force was exerted on the femur. A 3.5 mm rod was mounted on the tibia and made to pass through the slotted fixture of the plate. The tibia was freely movable without restriction except for the small friction occurring at the junction of the rod and fixture during the flexion-extension movement of the stifle [7] (**Fig. 1A**). The quadriceps tendon was stitched using a polyester suture (Ethibond Excel®, Ethicon Inc., USA) with the Krackow stitch method, connected to the stainless-steel cable with a turnbuckle; subsequently, 30% of the body-weight was applied using a weight-and-pully system. This quadriceps force was determined through preliminary experiments by referring to the patellofemoral contact pressure values of existing studies [6,8].

The measurement of the Q angle was based on the methods reported by Kaiser et al. [4]. The Q angle was defined as the angle between the course of the direction of the rectus
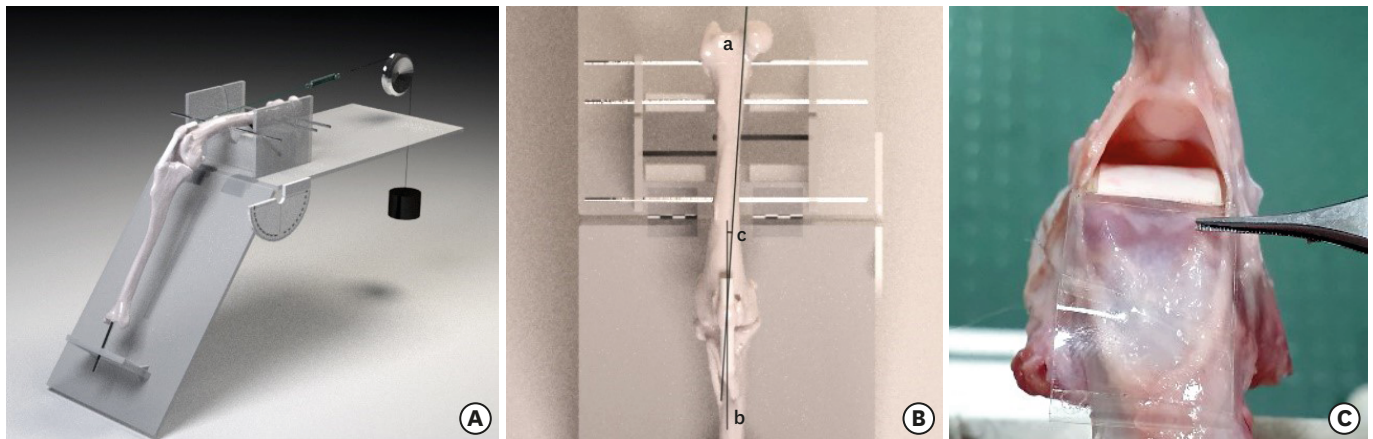
Fig. 1. Test apparatus, measurement of the quadriceps angle, and contact pressure measurement using pressure film. (A) Schematic diagram of the testing frame. The specimen extracted from the canine's cadaver is fixed to the frame, and the stifle part is kept free from the restriction for the flexion-extension movement. A load equivalent to 30% of the body-weight is exerted on the quadriceps tendon. (B) Adjustment of the quadriceps angle. The direction of the quadriceps force is adjusted according to the line of action of rectus femoris muscle (a) and an acute angle (c) formed with the patellar ligament (b). (C) Insertion of the pressure film in the patellofemoral joint. The film is inserted into the patellofemoral joint through the suprapatellar pouch incision. The film is 2 mm larger than the width and height measurements of the patella, and polyethylene film is attached on its front and back to prevent the entry of water.

femoris muscle and the patellar ligament. Informed by radiographic images taken before the experiment, the direction of the quadriceps force was set by marking the lines of action of the rectus femoris muscle on the femoral head. The angle was measured using protractor during stifle extension. The degree of increase or decrease was adjusted by moving the cables connected to the quadriceps tendon medially or laterally on the frontal plane (**Fig. 1B**).

The stifle flexion angle followed the definition reported by Dennler et al. [9] and was measured from the two long axes of the femur and tibia determined by the lines between the two shafts, with midpoints at one-third and two-thirds of the femoral and tibial lengths.

Contact pressure measurement

The patellofemoral contact area and pressure were measured using Fuji pressure-sensitive film (Prescale®, Fuji Photo Film Co., Ltd., Japan). A preliminary experiment was carried out to select the appropriate film, and super low pressure Prescale film capable of measuring from 0.5 MPa up to 2.5 MPa was selected. A 0.2 mm thick super low-pressure film consists of 'A' and 'C' layers; the 'A' layer contains microcapsules that rupture at a certain pressure and create red patches by reacting with the developer solution in the 'C' layer. The concentration of the red color indicates the level of local pressure applied.

The film was cut 2 mm larger than the width and height of the patella and measured in advance. Since the film was vulnerable to humidity, it was sealed with two sheets of self-adhesive polyethylene (Tegaderm®, 3M Health Care, USA) to prevent contamination by the damp atmosphere [10]. The film was then placed in the patellofemoral articulation by incising the suprapatellar pouch, and the beads that had been previously embedded were marked with a pen on the top of polyethylene film (**Fig. 1C**).

Testing protocol

The test was carried out under four conditions. Firstly, the normal condition that maintained the physiological Q angle was set as a baseline state. The second condition that caused malalignment by increasing the Q angle was where the trochlea pulling the quadriceps tendon was shifted
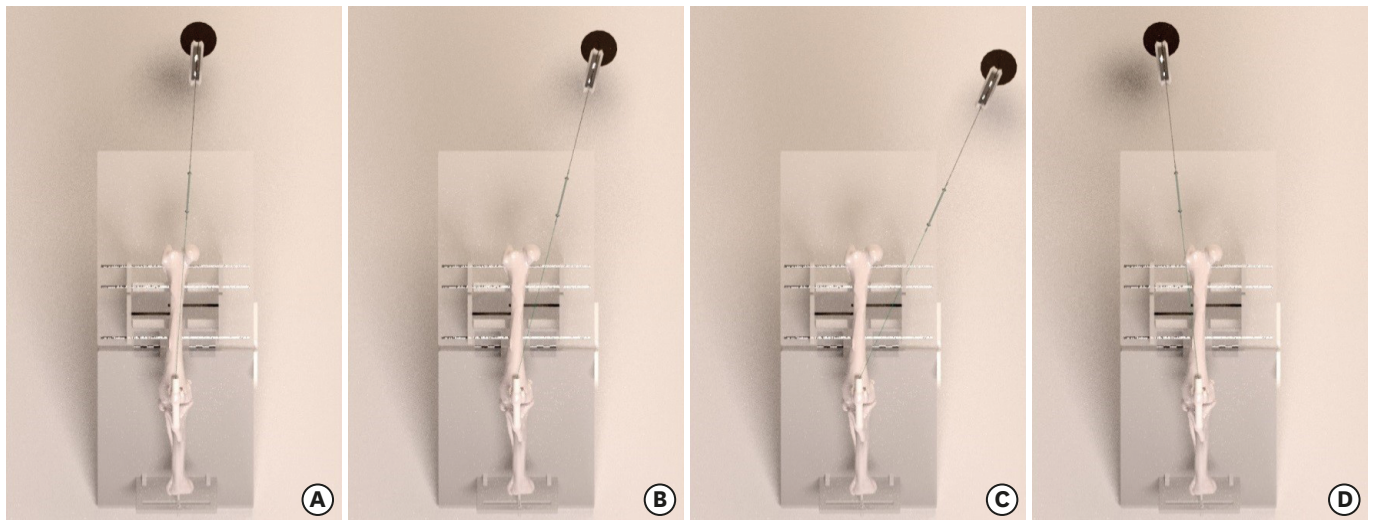
Fig. 2. Four testing conditions. (A) Normal, (B) Quadriceps angle is increased by 10°, (C) Quadriceps angle is increased by 20°, (D) Quadriceps angle is decreased by 10°.

medially and increased by 10°. The third condition that induced the Q angle corresponding to high-grade patellar luxation was where the Q angle was increased by 20° in the same manner. The fourth condition was where the trochlea was shifted laterally from the normal by 10° for the purpose of decreasing the Q angle [4] (**Fig. 2**). The test was carried out under the above four conditions while applying various degrees of flexion (45°, 60°, 75°, 90°, 105°, and 120°). Quadriceps loading was applied for 2 min, and an interval of 3 min was given for each test for the viscoelastic recovery of the joint cartilage [6]. Since the Prescale film is sensitive to temperature and humidity, the temperature of the experimental environment was maintained at 25°C with 36% humidity. On average, 2 to 3 Prescale films were used for each test. Films that had poor sealing properties, were affected by unwanted pressure during manipulation or produced artifacts during the placement of the film on the joint surface were all excluded from the test.
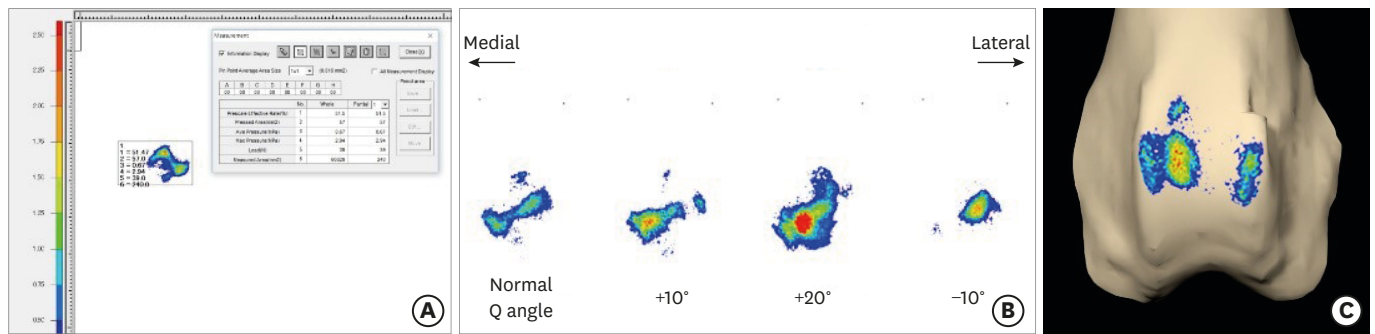
Data analysis

Results for pressure area, mean pressure, peak pressure, lateral peak pressure, and medial peak pressure were obtained by scanning the Prescale C layer using dedicated software (Fuji FPD-8010E, Fuji Photo Film Co., Ltd.) (**Fig. 3A**). The middle 2 mm portion of the femoral trochlear groove was excluded from the measurement of medial and lateral peak pressure. Pressure exceeding 2.5 MPa in the program was measured as 2.5 MPa, and pressure below 0.5 MPa was deleted due to the possibility of interference during manipulation.

By using the software Adobe Photoshop CS6 (Adobe System, USA), the scanned images were superimposed on the reference points (**Fig. 3B**). Three-dimensional (3D) images were created from the film images to estimate the actual pressure distribution on the bone. From a CT scan, a DICOM file was imported into InVesalius 3 software (Center for Information Technology Renato Archer, Brazil), and was converted into a 3D image format. Then, the pressure distribution image for each condition was obtained by overlaying the pressure distribution image using 3ds Max software (Autodesk, USA) (**Fig. 3C**).

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics version 24 (IBM, USA) for Windows. A Kolmogorov-Smirnov test was performed to establish whether the data showed

Fig. 3. Data analysis. (A) Pressure measurement using FPD-8010E. The Prescale effective rate, pressed area, average pressure, maximum pressure, load, and measured area values of the scanned film are calculated using the FPD-8010E program. Results are obtained by measuring pressure area, mean pressure, peak pressure, lateral peak pressure, and medial peak pressure. High pressure is represented by the hot (red) tone and low pressure by the cold (blue) tone color. Note the pressure reference bar on the left side. (B) Examples of contact imprints aligned to the reference points. The contact imprints are sorted by reference point. Q angle, quadriceps angle. (C) An example of the volume rendering procedure for estimating the actual pressure distribution on the bone. Variations in pressure distribution, size of the area, and intensity of the pressure depending on the changes in quadriceps angle are readily apparent.

normal distribution, and comparative analysis was carried out using repeated-measures ANOVA and Tukey's post hoc test to identify any significant differences between groups. For the peak contact pressure that did not show normal distribution as the upper limit value was limited to 2.5 MPa, a Mann Whitney *U*-test was performed for the comparative analysis. All the analysis results were statistically significant at $P \leq 0.05$.

RESULTS

Patellofemoral contact pressure distribution
As the stifle flexion of all samples increased, the point under pressure shifted distally, and the area decreased. Depending on the increase or decrease in the Q angle, the location of peak pressure tended to change along with direction change, and the amount of pressure showed a tendency to increase (**Fig. 4**).

Pressure area measurement
The area under pressure showed statistically significant increases in the groups where the Q angle was increased by 10° ($P = 0.040$) and 20° ($P = 0.021$), respectively, compared with the normal group. The pressure area decreased significantly at 105° ($P \leq 0.05$) and 120° ($P \leq 0.001$) than other stifle flexion angles (**Table 1**).

Mean pressure measurement
Mean pressure significantly increased in the groups where the Q angle increased by 10° ($P = 0.003$) and 20° ($P \leq 0.001$), as well as in the group where the Q angle decreased by 10° ($P = 0.013$), compared with the normal group. The group where the Q angle increased by 20° showed higher pressure than groups with Q angle increased or decreased by 10° ($P \leq 0.001$) (**Table 2**).

Peak pressure measurement
A significant increase in the peak pressure exerted on the joints was observed at 45° ($P = 0.005$), 60° ($P \leq 0.001$), 75° ($P \leq 0.001$), 90° ($P = 0.007$), and 105° ($P = 0.003$) where the Q angle increased by 10°. Also, a significant increase was observed in all instances where the Q angle increased by 20°. A significant increase was observed at 45° ($P = 0.004$), 60° ($P = 0.003$), 75° ($P = 0.012$), 105° ($P = 0.040$), at 120° ($P = 0.021$) with the decreased Q angle. The group where the
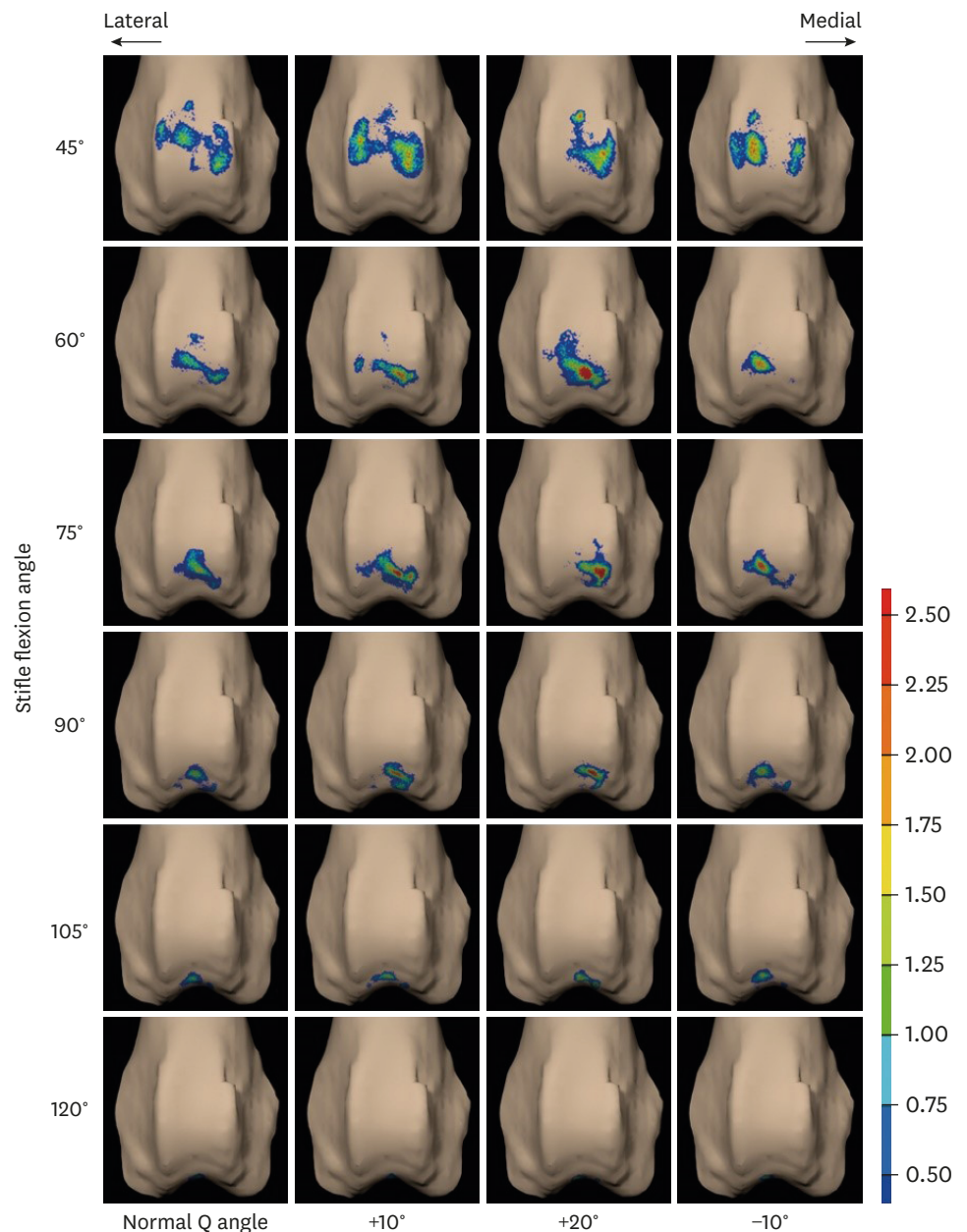
Fig. 4. Patellofemoral contact pressure distribution under the four different conditions of quadriceps angle: normal, +10°, +20°, and −10°. As the stifle flexion increases, the site under pressure shifts distally and the area decreases. If the Q angle increases, the area under high pressure expands on the medial trochlear facet, whereas if the Q angle decreases, the pressure is relatively focused on the lateral trochlear facet. High pressure is represented by the hot (red) tone and low pressure by the cold (blue) tone color. Note the pressure reference bar on the right side. Q angle, quadriceps angle.

Q angle increased by 20° demonstrated high-pressure exertion on the joints at 105° ($P \leq 0.001$) and 120° ($P = 0.031$) compared to the group where the Q angle increased by 10° (**Table 3**).

Medial peak pressure measurement
No significant difference was observed between the group with decreased Q angle and the normal group. A significant increase in the pressure in the medial trochlear facet was

Table 1. Pressure area value under the four conditions: normal, +10°, +20°, and -10° (unit: square millimeter)

Flexion angle	Normal Q angle[a]	+10°[b]	+20°[b]	−10°[ab]
45°	16.69 ± 2.79	19.81 ± 4.28	22.69 ± 7.45	19.13 ± 2.74
60°	14.69 ± 2.12	20.50 ± 5.35	19.94 ± 8.08	17.06 ± 3.08
75°	14.88 ± 2.60	20.69 ± 4.18	21.63 ± 4.88	15.69 ± 2.78
90°	14.31 ± 4.11	20.63 ± 5.75	18.88 ± 4.28	15.00 ± 3.60
105°	10.25 ± 3.31	16.00 ± 5.64	15.38 ± 5.03	12.88 ± 4.63
120°	6.94 ± 3.12	8.50 ± 2.59	10.50 ± 3.06	8.75 ± 1.85

Values represent means ± SD (n = 8).
Different superscripts indicate significant differences between groups ($P \leq 0.05$).
Q angle, quadriceps angle.

Table 2. Mean pressure value under the four conditions: normal, +10°, +20°, and −10° (unit: megapascal)

Flexion angle	Normal Q angle[a]	+10°[b]	+20°[c]	−10°[b]
45°	0.68 ± 0.06	0.75 ± 0.07	0.87 ± 0.11	0.78 ± 0.07
60°	0.64 ± 0.05	0.81 ± 0.08	0.95 ± 0.07	0.80 ± 0.10
75°	0.63 ± 0.06	0.81 ± 0.09	0.96 ± 0.09	0.73 ± 0.09
90°	0.66 ± 0.08	0.80 ± 0.11	0.96 ± 0.12	0.73 ± 0.07
105°	0.65 ± 0.07	0.68 ± 0.06	0.87 ± 0.12	0.70 ± 0.08
120°	0.60 ± 0.06	0.67 ± 0.05	0.77 ± 0.11	0.68 ± 0.06

Values represent means ± SD (n = 8).
Different superscripts indicate significant differences between groups ($P \leq 0.05$).
Q angle, quadriceps angle.

observed for the groups where the Q angle increased by 10° and 20°. At stifle flexion angles of 105° ($P \leq 0.001$) and 120° ($P = 0.023$), a significant increase in the pressure was observed in the group where the Q angle increased by 20° compared with the group where the Q angle increased by 10° (**Table 4**).

Lateral peak pressure measurement
When the Q angle decreased, the pressure exerted on the lateral trochlear facet increased significantly ($P \leq 0.001$). A significant difference was observed in all stifle flexion angles. No significant difference was observed when the Q angle was increased (**Table 5**).

Table 3. Peak pressure value under the four conditions: normal, +10°, +20°, and -10°. (unit: megapascal)

Flexion angle	Normal Q angle (1)	+10° (2)	+20° (3)	−10° (4)
45°	1.65 ± 0.20	2.13 ± 0.32 (**P_{1-2} = 0.005**)	2.33 ± 0.33 (**P_{1-3} = 0.003**) (P_{2-3} = 0.079)	2.09 ± 0.28 (**P_{1-4} = 0.004**)
60°	1.51 ± 0.19	2.41 ± 0.16 (**$P_{1-2} \leq 0.001$**)	2.50 ± 0.01 (**$P_{1-3} \leq 0.001$**) (P_{2-3} = 0.19)	2.12 ± 0.36 (**P_{1-4} = 0.003**)
75°	1.48 ± 0.28	2.39 ± 0.19 (**$P_{1-2} \leq 0.001$**)	2.50 (**$P_{1-3} \leq 0.001$**) (P_{2-3} = 0.16)	1.95 ± 0.31 (**P_{1-4} = 0.012**)
90°	1.77 ± 0.36	2.34 ± 0.43 (**P_{1-2} = 0.007**)	2.50 (**$P_{1-3} \leq 0.001$**) (P_{2-3} = 0.319)	1.97 ± 0.25 (P_{1-4} = 0.206)
105°	1.40 ± 0.16	1.82 ± 0.22 (**P_{1-2} = 0.003**)	2.38 ± 0.18 (**$P_{1-3} \leq 0.001$**) (**$P_{2-3} \leq 0.001$**)	1.69 ± 0.34 (**P_{1-4} = 0.04**)
120°	1.34 ± 0.23	1.58 ± 0.19 (P_{1-2} = 0.082)	2.01 ± 0.41 (**P_{1-3} = 0.002**) (**P_{2-3} = 0.031**)	1.61 ± 0.23 (**P_{1-4} = 0.021**)

Values represent means ± SD (n = 8).
P-values in boldface indicate significant differences between two groups ($P \leq 0.05$).
Q angle, quadriceps angle.

Table 4. Medial peak pressure value under the four conditions: normal, +10°, +20°, and −10° (unit: megapascal)

Flexion angle	Normal Q angle (1)	+10° (2)	+20° (3)	−10° (4)
45°	1.58 ± 0.26	2.17 ± 0.32 (**P_{1-2} = 0.005**)	2.33 ± 0.33 (**P_{1-3} = 0.003**) (P_{2-3} = 0.079)	1.41 ± 0.19 (P_{1-4} = 0.189)
60°	1.47 ± 0.19	2.41 ± 0.16 (**P_{1-2} ≤ 0.001**)	2.50 ± 0.01 (**P_{1-3} ≤ 0.001**) (P_{2-3} = 0.19)	1.27 ± 0.37 (P_{1-4} = 0.345)
75°	1.40 ± 0.33	2.39 ± 0.19 (**P_{1-2} ≤ 0.001**)	2.50 (**P_{1-3} ≤ 0.001**) (P_{2-3} = 0.16)	1.26 ± 0.26 (P_{1-4} = 0.529)
90°	1.37 ± 0.36	2.34 ± 0.43 (**P_{1-2} = 0.003**)	2.50 (**P_{1-3} ≤ 0.001**) (P_{2-3} = 0.319)	1.19 ± 0.17 (P_{1-4} = 0.345)
105°	1.02 ± 0.28	1.80 ± 0.19 (**P_{1-2} ≤ 0.001**)	2.38 ± 0.18 (**P_{1-3} ≤ 0.001**) (**P_{2-3} ≤ 0.001**)	1.05 ± 0.23 (P_{1-4} = 0.834)
120°	0.95 ± 0.19	1.54 ± 0.19 (**P_{1-2} ≤ 0.001**)	2.01 ± 0.41 (**P_{1-3} ≤ 0.001**) (**P_{2-3} = 0.023**)	0.94 ± 0.17 (P_{1-4} = 0.834)

Values represent means ± SD (n = 8).
P-values in boldface indicate significant differences between two groups (*P* ≤ 0.05).
Q angle, quadriceps angle.

Table 5. Lateral peak pressure value under the four conditions: normal, +10°, +20°, and −10° (unit: megapascal)

Flexion angle	Normal Q angle [a]	+10°[a]	+20°[a]	−10°[b]
45°	1.41 ± 0.28	1.43 ± 0.24	1.45 ± 0.47	2.09 ± 0.28
60°	1.26 ± 0.26	1.42 ± 0.21	1.18 ± 0.16	2.10 ± 0.39
75°	1.16 ± 0.23	1.28 ± 0.22	1.20 ± 0.24	1.91 ± 0.35
90°	1.39 ± 0.28	1.31 ± 0.23	1.12 ± 0.11	1.97 ± 0.25
105°	1.15 ± 0.25	1.34 ± 0.33	1.16 ± 0.27	1.69 ± 0.34
120°	1.18 ± 0.30	1.12 ± 0.25	1.10 ± 0.30	1.57 ± 0.26

Values represent means ± SD (n = 8).
Different superscripts indicate significant differences between groups (*P* ≤ 0.05).
Q angle, quadriceps angle.

DISCUSSION

An abnormal Q angle causes pain and induces degenerative changes in the joints as a result of the exertion of high pressure on the patellofemoral joints [11-13]. While the importance of the Q angle in terms of correcting patellar luxation in dogs is widely known [3,14,15], there is no evidence of proper degree for Q angle correction. In addition, it has been reported that correction surgery for patellar luxation does not prevent the progression of osteoarthritis, and it is considered that a comparative study of surgical methods is necessary in various aspects to prevent the progression of osteoarthritis [16]. In this study, the effect of Q angle on patellofemoral joint pressure according to the Q angle variation of the stifle joint of the dog was investigated.

Evaluation of direct contact pressure and the contact area is essential in understanding the loading environment of the joint. The Prescale pressure measuring system is useful in determining contact pressure and the contact area distribution pattern of the joint [6,10,11]. The film is suitable for measuring patellofemoral joint pressure as it can be cut into desired sizes, and it enables the selection of variable pressure ranges. This experiment was set up with an close chain and selected a super low Prescale film based on normal conditions. However, unlike the accurate measurement of pressure within the range in the normal groups, precise measurement in the group whose pressure exceeded 2.5 MPa due to increased Q angle was difficult as it was greater than the measurable range of the Prescale film. The results for peak pressure showed no significant differences at 45, 60, 75, or 90°, unlike those groups that showed significant differences where the Q angle increased by 20 and 10° respectively when the stifle was bent at 105 and 120°, which may be because the value was at the upper limit.

When the Q angle increased by 10°, the mean pressure, peak pressure, and medial peak pressure were found to increase significantly. Likewise, there was a significant increase in mean pressure, peak pressure, and lateral peak pressure when the Q angle decreased by 10°. Furthermore, a group where the Q angle increased by 20° was added in the experiment to test high-grade patellar luxation; as the angle increased, the increases in pressure became greater. This finding is in accordance with the results of previously reported human cadaver studies [11,17]. Although it is difficult to make simple comparison because the knees of humans and dogs are different, but it should be noted that abnormal Q angle is considered a potential cause of chondromalacia in humans and many studies have been conducted. Based on this, the results of this study can be interpreted that fluctuations in the Q angle causes an increase in contact pressure by inducing instability, and the greater the change, the greater the increase in pressure.

The patellofemoral contact area tended to decrease as the stifle bent. The more the stifle bends kinematically, the more it is positioned in the distal aspect of the trochlear groove, and only a portion of patella tends to articulate [18]. Although its role has not yet been investigated in dogs, the contact between the quadriceps tendon and the femoral trochlea groove may contribute to reducing the patellofemoral pressure when the stifle flexion angle is large [11].

The mean values of both the contact area and pressure tended to increase when there was variation in the Q angle. Although some researchers report that locally acting pressure increases as the contact area decreases [11,19], in this test, the appearance of the radial distribution of pressure around the point of maximum pressure is due to an increase in the contact area between cartilages in proportion to increasing pressure. This increase in contact area is due to the inherent viscoelastic nature of the articular cartilage when pressure is applied continuously for 2 min [20]. Also, because of the technical limitations of pressure-sensitive films, very low pressures cannot be measured, so the relationship between area and pressure needs to be studied further.

This study being an *in vitro* study using legs of healthy beagles cannot fully reproduce the effect of an abnormal Q angle acting on the stifles *in vivo*. We adjusted the Q angle variable only at the origin, not at the distal point, and so did not assess the effects of changes such as a medial shift of the tibial tuberosity or excessive internal rotation of the tibia. Also, secondary musculoskeletal changes due to abnormal Q angle could not be reproduced. In clinical trials, dogs with increased Q angle often have increased lateral distal femoral angle, shallowed trochlea, and injury to the support tissue, so the patella will easily dislocate under the conditions of this experiment. Therefore, it is important to note the relative changes rather than giving absolute meaning to interpreting the results of this experiment. In this experiment, the pressure was measured under the quadriceps load of 30% of the body weight in the direction of the rectus femoris muscle under static conditions. For experiments similar to *in vivo*, it is thought that the strength of each muscle distributed in the dog's hind limb should be revealed through additional research. A more accurate experiment would be possible if different physiological loads were applied to each subdivisions of the quadriceps muscle, and loads were also applied to surrounding muscles such as hamstring and gastrocnemius muscles. Also, depending on the posture and conditions, the force applied to the patellofemoral joint will also be changed significantly, so further research should be supported.

In the study, the pressure on the patellofemoral joint was measured between 0.5 to 2.5 MPa or more. Although significant differences have been seen with changes in Q angle, it is not

clear whether differences in pressure at that level actually mean enough to cause changes in cartilage or cause pain. In addition, due to the nature of the dog's species, the weight variation between breeds is large and the anatomical characteristics are different, so the pressure may also be different.

Accurate preoperative evaluation and intraoperative measurements are important for proper correction of the Q angle. In this study, accurate calculations were made because the Q angle was measured with a protractor by looking at the patellar ligament and rectus femoris muscle directly on the leg fixed to the frame. However, since the origin of the rectus femoris muscle at the body of the ilium is difficult to identify due to the limited surgical incision, the measurement method using a protractor will be practically limited. Clinically, Q angles of dogs were measured by radiograph, CT, and magnetic resonance measurements [4,21]. In the future, further research on the reliability and accuracy of the measurement method would be desirable.

This study provides baseline data of the patellofemoral contact area and pressure obtained by *in vitro* measurement in the normal stifle of dogs. The peak patellofemoral pressure that can contribute to cartilage damage increases with the change in Q angle and the pressure increment were in proportion to the degree of variation in the Q angle. To conclude, correction of the Q angle needs to be considered to prevent the risk of degenerative changes as a consequence of an inappropriate Q angle, but overcorrection of the Q angle should be avoided.

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