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Original Article

Volume and mobility of the infrapatellar fat pad during quasi-static knee extension after manual therapy in patients with knee osteoarthritis: a randomized control trial study

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Abstract. [Purpose] This study aimed to determine whether the volume and mobility of the infrapatellar fat pad (IPFP) change as a result of manual release or stretching during quasi-static knee extension in patients with knee osteoarthritis (KOA). [Participants and Methods] Fourteen patients with KOA were allocated to one of two groups: the manual release (R) and stretching (S, control) groups. They all underwent 12 treatment sessions in in a space of four weeks. We created 3D models of the IPFP, tibia, patella, and patellar tendon using sagittal MRI scans with the knee at 30° or 0°. We compared the differences in (1) the distance of anterior movement of the anterior surface of the IPFP (IPFP movement) and (2) the volume of the IPFP, between the R and S groups, using the 3D models. [Results] Neither group showed any anterior movement of the IPFP during quasi-static knee extension at pre-intervention; however, both groups showed significant anterior movement of the IPFP at post-intervention. IPFP movement decreased in the S group, meanwhile it increased in the R group at post-intervention. [Conclusion] Anterior movement of the IPFP was more increased by manual release than by stretching since the latter may have shortened the distance between the patella and tibial tuberosity at 0° and 30° flexion.
Key words: Infrapatellar fat pad, Knee, Knee osteoarthritis

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INTRODUCTION

Knee osteoarthritis (KOA) is an irreversible degenerative disease, in which the principal complaint is pain during loading, including walking[1)]. Pain and functional deterioration caused by KOA negatively impact activity of daily living (ADL)[2)]. The morbidity rate of KOA with a secondary decline in ADL increases with age and causes a heavy burden on patients and society[3)]. Therefore, it is necessary to improve therapeutic methods for KOA. The infrapatellar fat pad (IPFP) may be associated with progression of KOA[4)], because KOA often involves inflammation of the IPFP, causing greater production of collagen fibers and fibroblasts. We have reported that patients with KOA manifest reduced IPFP movement during quasi-static knee extension from 30° to 0° (QSKE), compared with young, healthy individuals. However, it is unclear whether IPFP movement in patients with KOA can be increased by physical therapy, and whether it improves patient outcomes.

Conservative treatment, including physical therapy, would be the first choice in early to moderate KOA, possibly including exercises, manual therapy, modalities, braces, orthotics, and medication[5)]. Though many studies have proven that

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conservative treatment is effective for moderate symptoms and that it enhances function[6–8], pain and functional deficits often persist[9]. The IPFP space, or the space in front of the knee, should change shape and volume during knee movement[10], which requires shape change of the IPFP. Stiffness of the IPFP that occurs in KOA may limit movement of anatomical structures around the IPFP. No therapeutic method has been proposed to reduce stiffness of the IPFP. Therefore, the aims of this study were 1) to determine whether combined manual and exercise therapy are effective at reducing the stiffness of the IPFP in KOA during QSKE, and 2) to determine whether the therapy is effective at reducing knee pain and improving function in patients with KOA.

Manual therapy for the IPFP has not been proposed in the literature. Reduced gliding between structures, associated with stiffness, may be improved by manual therapy targeted to the fascia connecting adjacent structures. Tozzi et al.[8] showed that sliding motion of fascial layers and low back pain were improved with myofascial release (MFR). Kain et al.[7] reported that indirect MFR over the gleno-humeral joint and clavi-pectoral region for 3 min increased shoulder range of motion (ROM). The MFR in both studies targeted the fascia in subcutaneous tissue, which may have improved gliding of the skin and muscles. Therefore, fascial release around the IPFP in KOA may improve gliding between the IPFP and surrounding structures, reducing stress on the IPFP. On the other hand, stretching could be a form of exercise therapy to improve inter-structural gliding. Aoki et al.[11] reported that static stretching in KOA improved knee flexion ROM by 9.5 ± 16.2% and reduced knee pain significantly. KOA should involve pathokinematics with reduced knee internal rotation during flexion[12–14]. Yoshida et al.[9] reported a case series in which an exercise program involving tibial internal rotation improved knee pain and function. Our unpublished study showed significant reduction in Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores using the same exercise program. Benefits of strength training in patients with KOA were documented in a systematic review[6], in which most studies reported that strength training ameliorated KOA symptoms and improved function by clinically meaningful amounts. Combining these interventions may reduce stiffness of the IPFP in KOA.

The first hypothesis of this study was that mobility of the IPFP in patients with KOA during QSKE would be improved by combined manual and exercise therapy. The second hypothesis was that shape change of the IPFP is associated with patellar mobility and alignment, as well as tibial mobility in patients with KOA. The third hypothesis was that combined manual and exercise therapy would reduce pain in patients with KOA. This study was intended to help us understand the role of IPFP mobility and its potential therapeutic benefits in conservative treatment for KOA.

PARTICIPANTS AND METHODS

This was a small randomized control trial and the level of evidence was II. After obtaining approval from the local ethics committee, we recruited patients with KOA at a local hospital. Inclusion criteria for the KOA group were: 1) age 40 to 79 years at the time of recruitment, and 2) Kellgren-Laurence classification of 1–4. Exclusion criteria for patients were: 1) history of surgery or fracture of either lower limb, 2) problems with communication, 3) difficulty in understanding the study, 4) pregnancy, 5) medical risks, or 6) rheumatoid arthritis. Fourteen patients who agreed to participate in this study were randomly and evenly allocated using a computer-generated random table into either a combined manual release and exercise therapy group (R group; 63.6 ± 6.5 years) or a combined stretching and exercise group (S group; 65.1 ± 8.5 years) (Table 1).

After obtaining written consent, all pre-intervention measurements, including MRI scanning, were performed. Interventions were performed twice a week for four weeks. All interventions were supervised by a researcher. Outcome measure-

Table 1. Demographic data for all participants

	R group	S group	p value
Male	1	2	-
Female	6	5	-
Age (years)*	63.6 ± 6.5	65.1 ± 8.5	0.363‡
BMI (kg/m^2)*	22.8 ± 3.7	25.1 ± 2.4	0.371‡
Knee flexion angle (degrees)*	146.1 ± 8.6	146.9 ± 6.7	0.438‡
Knee extension angle (degrees)*	6.3 ± 2.4	1.4 ± 4.0	0.012‡
Q-angle*	20.6 ± 4.5	21.1 ± 6.0	0.428‡
K/L I	1	0	-
K/L II	6	4	-
K/L III	0	1	-
K/L IV	0	2	-

Data are presented as means ± SD.
*: data are presented as the mean ± standard deviation.
‡: Student t-test.
R group: Manual release group; S group: Stretch group; BMI: body mass index; K/L: Kellgren Lawrence grade; Q-angle: quadriceps angle.

ments were performed at 4 weeks. Researchers who performed measurements and analyses were blinded as to patient group assignments; however, therapists and participants were not.

An intervention session lasted 40 min, including 10 min of co-interventions, 10 min of intervention for each group, and 20 min of icing. Co-interventions included quadriceps setting and tibial internal rotation exercise using a special leg press training device (ReaLine Legpress, GLAB Corp., Hiroshima, Japan)[15] (Fig. 1). Then, the R group received manual release on the knee for 10 min by a physical therapist, while the S group received static stretching of the lower extremity for 10 min by the physical therapist. Icing was performed using ice cubes in a plastic bag applied to the anterior aspect of the knee.

Manual release was employed on the superficial fascia of the anterior knee by physical therapists who had been trained in the manual release technique for more than 6 years. The maneuver consisted of pinching with the thumb and index finger, with the tip of the distal phalanx (or releasing point) precisely at the superficial fascia around the IFPF, similar to a skin rolling technique (Fig. 2). When the release point on the distal phalanx hits the superficial fascia, it causes very sharp pain, which was adjusted so as to be below the visual analog scale of 5 and became almost pain free within 3 s, as releasing progressed. Synchronized with pain reduction, the resistance that therapists felt at the release point was reduced, so that the therapist could confirm that the release was complete. This technique (called inter-structural release or ISR) was developed by the senior author (KG) and requires a few months of training to master. We expected this method would improve gliding between the skin and IPFP, inducing greater mobility of the IPFP. The therapists cautiously applied ISR on the IFPF to avoid compression, because the IPFP can be damaged and inflamed[3, 16].

Static stretching was performed by another physical therapist on the hamstrings, triceps surae, quadriceps, adductors, and abductors (Fig. 3). Patients were in the supine or prone position, and received passive stretching for 30 s on each muscle group. The applied force on each muscle group was adjusted so that it caused a feeling of stretching without pain.

Age, body mass index (BMI), and Kellgren Lawrence (K/L) grade were measured at pre-intervention. Range of motion (ROM) of the knee, Visual Analog Scales (VAS), quadriceps angle (Q-angle), knee alignment, and the behavior of the IPFP were measured. ROM, Q-angle, and VAS were evaluated by two blinded physical therapists using a goniometer. Measures for knee alignment and behavior of the IPFP involved (1) movement of the IPFP, (2) volume change of the IPFP, (3) position of the patella, (4) changes in the surface length of the patellar tendon, (5) changes in the patellar tendon angle relative to the tibia, and (6) position of the femur using 3D models of the patella, patellar tendon, femur, tibia and IPFP from MRI taken at 0 and 30° knee flexion. These measures were analyzed by blinded researchers.

Analytical methods have been detailed previously[17]. First, MRI of the knee was taken using a 0.3T APERTO (Hitachi Medical Corporation, Tokyo, Japan) at 0° and 30° knee flexion while participants were in the supine position. The imaging sequence was 3D T1 of sagittal images with a slice pitch of 1 mm spanning 250 mm across the knee (TR:3700 TE:90). Second, 3D models of each anatomical body were created using 3D-Doctor (Able Software, Lexington, MA, USA). The shape of the IPFP was compared by two independent investigators using the best-fit algorithm of Geomagic software (Geomagic Corp., Research Triangle Park, NC, USA) and the measurement error evaluated by the surface difference was within 1.0 mm (Fig. 4). Third, coordinate systems were embedded in the femur, tibia, and patella using commercial 3D-Aligner software (GLAB Corp.)[12, 18] (Fig. 5).

Fig. 1. The tibial internal rotation exercise using a special leg press training device (ReaLine Legpress, GLAB Corp.).

Fig. 2. Manual release of the superficial fascia.
The maneuver of manual release consisted of pinching with the thumb and index finger, with a small tip of the distal phalanx (or releasing point) was precisely at the superficial fascia around the IFPF as skin subcutaneous tissue and patellar tendon.

Methods to obtain movement of the knee and IPFP were also described elsewhere[17]. Knee positions corresponding to the 6 degrees-of-freedom of the tibia were calculated with regard to the femoral 3D coordinate system, using the joint coordinate system proposed by Andriacchi et al.[19]

The IPFP is not a rigid body and its movement cannot be measured using a coordinate system. Instead, we determined the position of the anterior contour of the IPFP by averaging coordinates of 9 points on the anterior contour. Anterior movement of the IPFP or IPFP movement was the change in the position of the averaged anterior contour of the IPFP at 30° subtracted from the IPFP position at 0° on the tibial coordinate system.

The IPFP model was divided into eight hyperoctants divided by three planes. Specifically, the tibial XY plane (or sagittal plane), the tibial ZY plane (or horizontal plane) and a coronal plane parallel to the tibial YZ plane through the most anterior surface of the tibial tubercle. Then, the divided IPFP models in each hyperoctant at 30° were subtracted from the divided IPFP models at 0° to determine the volume changes in each hyperoctant (Fig. 6).

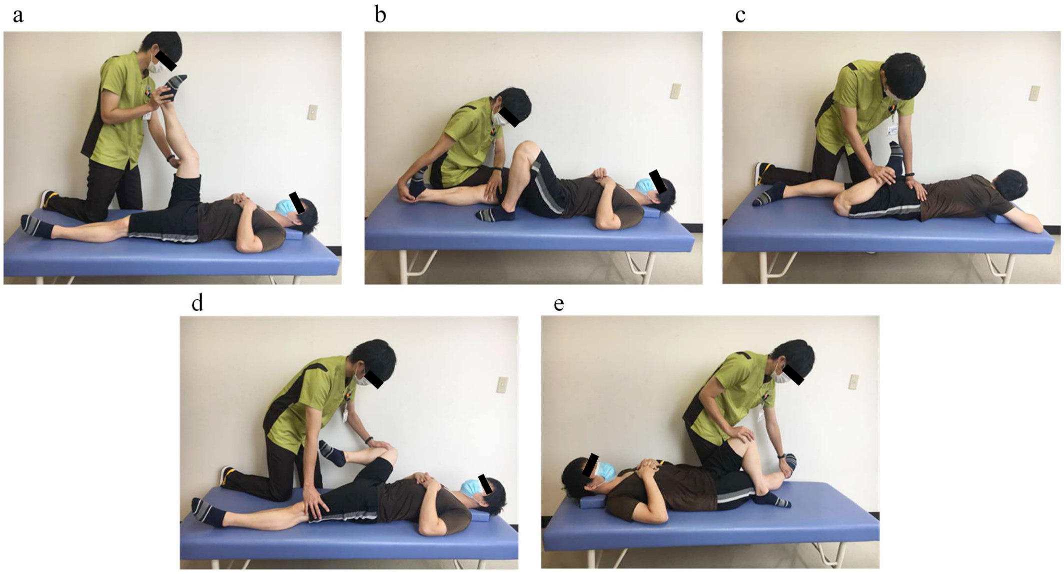

Fig. 3. Intervention of static stretch group.
The therapists intervened static stretching to patients with KOA. The static stretching was performed on the hamstrings (a), triceps surae (b), quadriceps (c), adductors (d), and abductors (e).

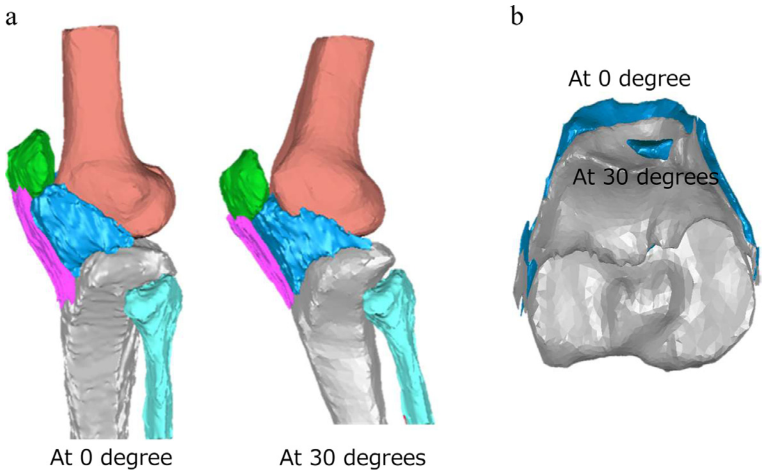

Fig. 4. Created 3D models of femur, tibia, fibula, patella, patellar tendon, Infrapatellar fat pad (left knee).
a. Sagittal MRI were taken at 0 and 30° flexion in the supine position. 3D models using 3D-Doctor software (Able Software) were created. Blue indicates the IPFP, gray the tibia, green the patella, pink the patellar tendon, orange the femur and sky blue fibula.
b. The IPFP at 0 and 30 degrees are overlaid relative to the tibia. (This picture sees tibial from the top and blue one is the IPFP at 0 degree and the IPFP at 30 degrees and tibia are gray.)

Change in patellar position was defined as the difference in the position of the patellar origin at 0° subtracted from that at 30° on the tibial coordinate system (Fig. 6).

Patellar distance was defined as the distance between the inferior pole of the patella and tibial tubercle on the tibial coordinate system. The measurement was performed using Geomagic software.

The patellar tendon angle was defined as the angle between the tibial longitudinal (Y) axis and the line connecting the inferior pole of the patella and the tibial tubercle on the XY plane (sagittal plane) of the tibial coordinate system. The measurement was performed using Geomagic and ImageJ software.

The surface length of the patellar tendon was measured using Geomagic software (Fig. 6).

Femoral movement was defined by the 6-degree-of-freedom movement of the femur on the tibia from 30° to 0° flexion using the joint coordinate system proposed by Andriacchi et al.[19]

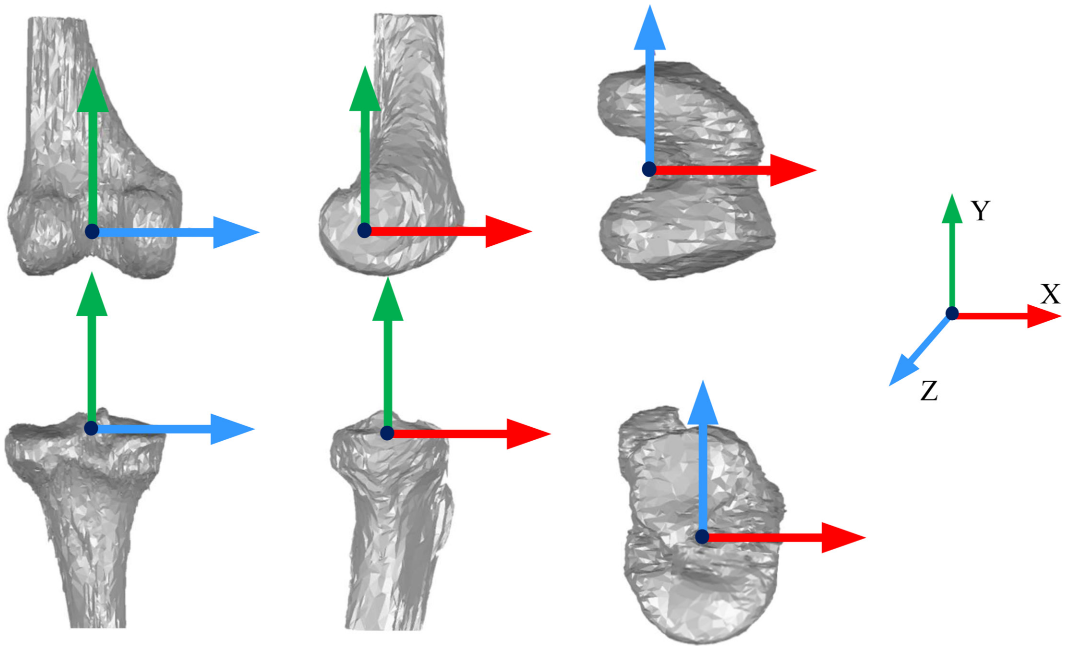

Fig. 5. Coordinate systems were embedded in the femur, tibia and patella (left knee).
Local coordinate system for the femur, tibia and patella were embedded using commercial 3D-Aligner software (GLAB Corp.). The X axis was directed anteriorly, Y superiorly and Z to the right.

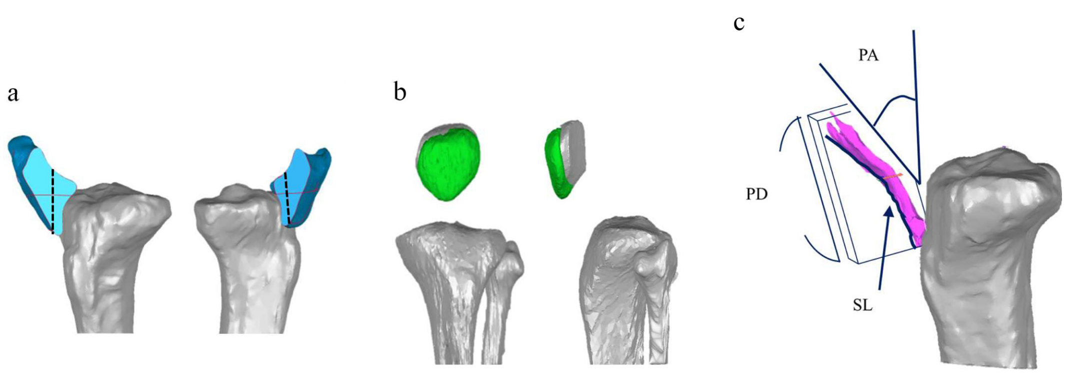

Fig. 6. Definitions of measuring outcomes explained below (left knee).
a. The IPFP model was divided into eight hyperoctants divided by three planes. Specifically, the tibial XY plane (or sagittal plane) at which the IPFP is cut on the figure, the tibial ZY plane (or horizontal plane) indicated in a solid line, and a coronal plane parallel to the tibial YZ plane indicated in the dotted line through the most anterior surface of the tibial tubercle.
b. Change in patellar position was defined as the difference in the position of the patellar origin at 0° shown in green subtracted from that at 30° shown in gray on the tibial coordinate system.
c. Patellar distance (PD), patellar tendon angle (PA), surface length of the patellar tendon (SL).

χ^2 tests were used to assess differences in males and females between the groups. The significance level was set at alpha=0.05. Comparisons between groups and within a group were performed using paired t-tests with Bonferroni correction. Three pairwise comparisons involved knee movements between knee positions, intra-group comparisons for both groups, and an inter-group comparison of changed values between 0° and 30°. Therefore, the final alpha after correction was 0.0167. The significance level was set at alpha=0.05. SPSS ver.14 was used for statistical tests. A post-hoc power analysis was performed using data derived[17]) from movement of the IPFP to obtain post-hoc power.

RESULTS

Of nineteen participates enrolled, four dropped out because they couldn't continue the intervention for personal reasons, and one was excluded for incomplete data. Therefore, fourteen participants (seven in each group) were analyzed. Average ages in the R and S groups were 63.6 [95% CI ;58.8, 68.4] years (male: female=1:6) and 65.1 [58.8, 71.4] years (male: female=2:5), respectively (Table 1). Knee extension angle was greater in the R group than the S group at pre-intervention, but the two groups showed no other significant differences.

Both the R and S groups showed that the anterior contour of the IPFP did not move from 30° to 0° at pre-intervention, while they moved anteriorly at post-intervention ($p<0.0167$). Mean IPFP movement for the R and S groups were 4.1 [2.4, 5.8] mm (p=0 0.003) and 2.8 [1.7, 3.9] mm (p=0.003), respectively, with no difference between the groups (Fig. 7, Table 2).

The R group showed no significant changes at pre-intervention in IPFP volume of any of the eight hyperoctants during QSKE. At post-intervention, the R group showed a decrease in volume in the postero-supero-lateral hyperoctant from 3,870.8 [3,173.9, 4,568.0] mm^3 to 2,118.0 [1,514.7, 2,721.2] mm^3 (p=0.010) from 30° to 0°, respectively (Fig. 8, Table 2). At pre-intervention, the S group showed a decrease in the postero-supero-lateral hyperoctant and an increase in antero-infero-lateral hyperoctant during QSKE. There was a decrease in IPFP volume in the postero-suoero-lateral hyperoctant from 4,813.2 [3,180.4, 6,446.1] mm^3 to 2,555.8 [1,278.8, 3,832.8] mm^3 (p=0.003) and also an increase in IPFP volume in the antero-infero-lateral hyperoctant from 889.6 [442.8, 1,336.3] mm^3 to 1,624.9 [944.5, 2,341.3] mm^3 (p=0.012). At post-intervention, the S group showed a decrease in the postero-supero-lateral hyperoctant during QSKE. Only the postero-suoero-lateral hyperoctant showed a decrease in IPFP volume during QSKE from 4,146.2 [2,796.6, 5,495.8] mm^3 to 2,154.9 [1,409.2, 2,900.6] mm^3 (p=0.002) after intervention.

Patellar position relative to the tibial coordinate system showed no significant change in either group during QSKE either at pre-intervention or after intervention (Table 3).

At pre-intervention, neither group showed a change in the distance from the patellar inferior pole to the tibial tuberosity during QSKE. After intervention, the R group showed a decrease in patellar distance from 30° to 0°, from 62.7 [58.0, 67.3]° to 50.0 [47.4, 52.2]° (p=0.003), respectively. Those for the S group were 64.5 [58.1, 70.9]° to 57.4 [50.0, 64.8]°(p=0.080), respectively, demonstrating no significant difference between 30° and 0° (Table 4).

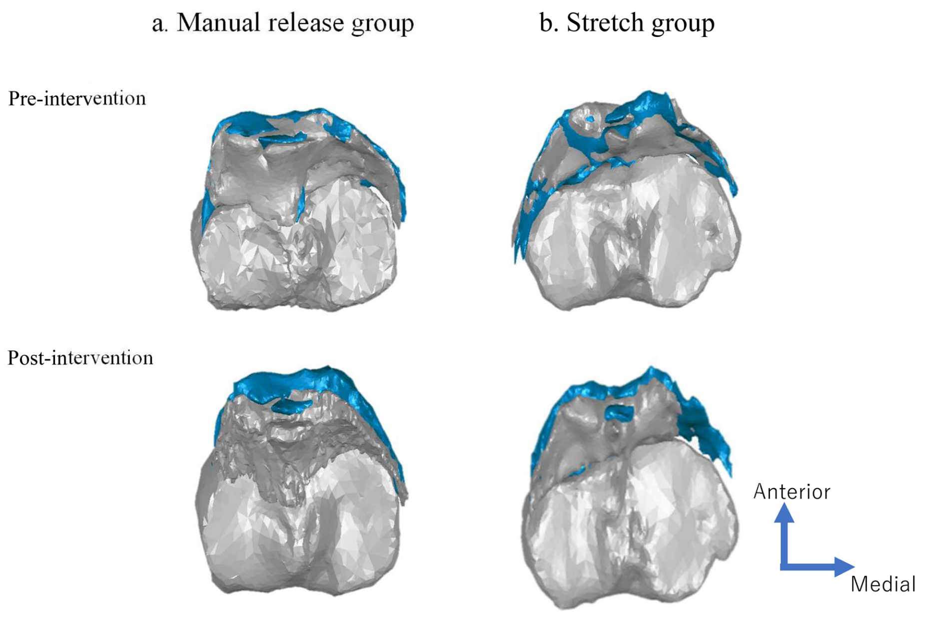

Fig. 7. Amount of IPFP movement (left knee).
The anterior movement of the infra-patellar fat pad (IPFP) during the quasi-static knee extension from 30 to 0° at pre- and post-intervention.

At pre-intervention, patellar tendon angle showed no significant changes during QSKE in both groups. At post-intervention, both groups showed an increase in patellar tendon angle from 30° to 0°. In the R group, patellar tendon angles at 30° and 0° were 26.6 [24.1, 29.1]° and 35.9 [32.9, 38.9]° (p=0.002), respectively. Those for the S group were 25.9 [23.9, 27.9]° to 30.7 [28.4, 33.1]° (p<0.001), respectively (Table 4).

Table 2. The results of the IPFP movement and volume at pre and post-intervention

		Manual release group						Stretch group					
		Pre			Post			Pre			Post		
		0°	30°	p-value	0°	30°	p-value	0°	30°	p-value	0°	30°	p-value
IPFP movement (mm)		38.8	37.1	0.172	39.3	35.2	0.003	37.9	34.9	0.020	37.3	34.5	0.003
IPFP Volume*1	Antero-supero-medial (mm^3)	4,146.2	3,932.4	0.309	4,169.3	3,755.4	0.721	5,500.8	4,688.7	0.055	3,566.9	3,723.5	0.847
	Postero-supero-medial (mm^3)	554.9	994.6	0.188	699.2	1,537.2	0.072	815.4	2,121.6	0.020	477.6	1,172.5	0.089
	Antero-supero-lateral (mm^3)	4,133.1	3,943.8	0.488	3,805.7	3,733.0	0.834	5,103.8	4,924.6	0.663	3,545.6	4,662.2	0.237
	Postero-supero-lateral (mm^3)	2,532.9	3,839.5	0.191	2,118.0	3,870.8	0.010	2,555.8	4,813.2	0.003	2,154.9	4,146.2	0.002
	Antero-infero-medial (mm^3)	825.5	734.1	0.829	999.2	521.5	0.145	1,042.8	457.9	0.033	762.0	402.5	0.060
	Postero-infero-medial (mm^3)	271.6	222.5	0.163	385.4	271.1	0.708	382.7	368.9	0.721	311.8	228.0	0.253
	Antero-infero-lateral (mm^3)	1,262.2	1,139.4	0.757	1,369.9	920.4	0.120	1,642.9	889.6	0.012	1,297.7	811.5	0.038
	Postero-infero-lateral (mm^3)	2,509.9	2,342.3	0.344	2,593.2	2,026.7	0.050	2,316.2	1,862.6	0.017	2,354.8	1,943.8	0.053

IPFP: infrapatellar fat pad.
*1: IPFP was divided into 8 hyperoctants based on the tibial coordinate system and the data shows the volume of IFPF in each hyperoctant.

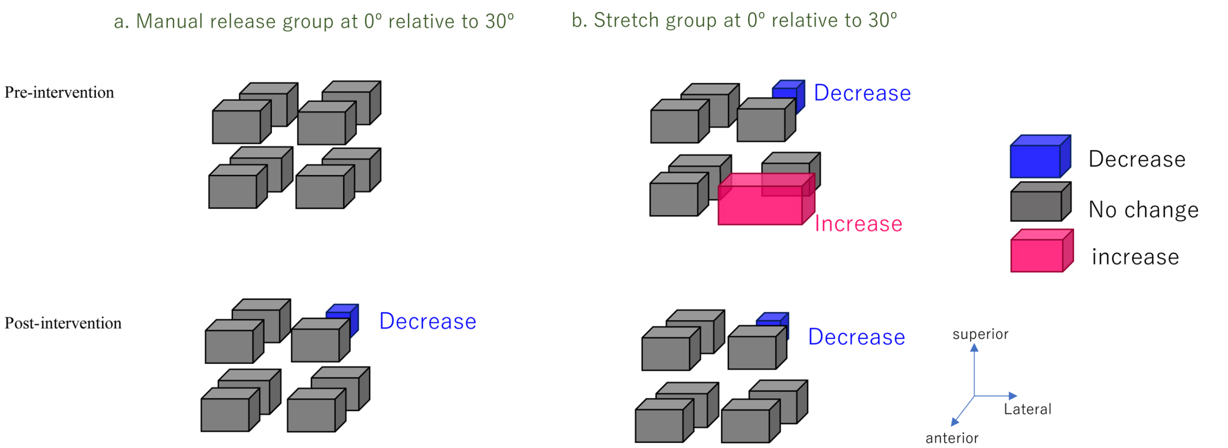

Fig. 8. The IPFP volume at 0º of manual release and stretch groups at both sides using divided cube models representing relative volume of the eight portions of the IPFP as compared with the equally-sized cubes at 30º. Blue cube indicates significant decrease, pink significant increase, and grey unchanged.

Table 3. The results of the patellar position at pre and post-intervention

		Manual release group (R group)						Stretch group (S group)					
		Pre			Post			Pre			Post		
		0°	30°	p-value	0°	30°	p-value	0°	30°	p-value	0°	30°	p-value
Patella position	Anterior translation (mm)	47.6	46.4	0.790	48.0	43.5	0.138	47.6	43.9	0.823	47.8	44.4	0.621
	Superior translation (mm)	26.8	28.5	0.803	26.5	30.0	0.167	30.2	33.9	0.757	30.0	33.1	0.318
	Medial translation (mm)	−4.3	−4.0	0.588	−5.3	−4.5	0.732	−5.0	−4.1	0.126	0.3	−0.6	0.100
	Internal rotation (°)*1	−2.2	−1.3	0.254	0.5	−0.1	0.647	−1.5	−1.8	0.071	1.3	0.0	0.382
	External tilt (°)*2	5.2	6.8	0.880	4.2	4.9	0.788	6.3	3.7	0.627	4.5	4.6	0.827
	Anterior rotation (°)	−14.2	−5.2	0.892	−14.5	−9.9	0.210	−11.3	0.8	0.779	−11.9	−5.0	0.030

*1: Internal rotation is the frontal plane rotation with the inferior pole directed medially.
*2: External tilt is the horizontal plane rotation with the lateral boarder moving posteriorly.

In both groups, the surface length of the patellar tendon showed no significant changes from 30° to 0° at pre-intervention or after intervention during quasi-static knee extension. Surface lengths of the patellar tendon at 30° and 0° in the R group were 50.5 [46.5, 54.5] mm and 44.0 [39.7, 48.2] mm (p=0.044), respectively. Those for the S group were 54.2 [47.8, 60.6] mm and 50.1 [43.1, 57.2] mm (p=0.168), respectively (Table 4).

In both groups, femoral movement showed no significant changes during QSKE at pre-intervention or after intervention (Table 5).

Q-angle was decreased in the S group from 21.1 [16.3, 26.0]° to 16.4 [12.0, 20.9]° (p=0.015) from 30° to 0°, respectively. Those for the R group showed no significant change from 20.6 [17.0, 24.2]° to 15.3 [11.1, 19.5]° (p=0.104) from 30° to 0°, respectively. ROM and VAS showed no significant differences after intervention in either group (Table 5).

DISCUSSION

The first hypothesis of this study was that mobility of the IPFP in patients with KOA during QSKE would improve as a result of combined manual and exercise therapy. Overall, anterior movement of the IPFP increased in both groups of KOA patients after intervention during quasi-static knee extension. IPFP volume of the eight hyperoctants in the R group showed no changes between knee positions at pre-intervention, whereas that of the postero-supero-lateral hyperoctant decreased after manual release. IPFP volume of two hyperoctants in the S group showed significant changes between knee positions at pre-intervention, whereas only one hyperoctant showed a significant change after intervention. The second hypothesis was that shape change of the IPFP is associated with patellar mobility and alignment, as well as tibial mobility in KOA patients. However, shape change of the IPFP was not correlated with patellar mobility, patellar alignment, or tibial mobility in KOA patients. The third hypothesis was that combined manual and exercise therapy would reduce pain in patients with KOA. There were no changes in VAS in either group.

There was greater movement of the posterolateral part of the IPFP during knee extension to accommodate movement of the femorotibial (FT) joint after manual therapy, while fewer hyperoctants of the IPFP moved after stretching, compared with pre-intervention. The IPFP exists in the anterior compartment of knee joint in front of the FT joint distal to the patella, which is required to accommodate both FT and PF movement. Bohnsack et al.[10] reported that shape and volume of the anterior compartment of the IPFP should change during knee motion. The smallest volume of the IPFP space was measured

Table 4. The results of the patellar tendon (surface length and angle), patellar distance at pre and post-intervention

	Manual release group (R group)						Stretch group (S group)					
	Pre			Post			Pre			Post		
	0°	30°	p-value	0°	30°	p-value	0°	30°	p-value	0°	30°	p-value
Patellar tendon												
Surface length (mm)	47.3	48.9	0.533	44.0	50.5	0.044	47.5	52.0	0.086	50.1	54.2	0.168
Patellar distance (mm)*1	48.5	50.8	0.544	50.0	62.7	0.003	50.2	58.8	0.093	57.4	64.5	0.080
Patellar tendon angle (°)	28.1	28.4	0.940	35.9	26.6	0.002	33.4	27.6	0.075	30.7	25.9	<0.001

*1: Distance between the inferior pole of the patella and tibial tuberosity.

Table 5. The results of the femoral movement and physical assessment at pre and post-intervention

		Manual release group						Stretch group					
		Pre			Post			Pre			Post		
		0°	30°	p-value	0°	30°	p-value	0°	30°	p-value	0°	30°	p-value
Femur	Anterior translation (mm)	−4.3	−3.6	0.321	−3.7	−5.2	0.395	−3.7	−5.6	0.791	−3.8	−5.1	0.554
	Superior translation (mm)	25.8	21.6	0.215	26.4	23.3	0.326	25.0	22.8	0.890	25.1	22.4	0.379
	Medial translation (mm)	0.4	−0.1	0.313	1.6	1.7	0.025	1.5	1.6	0.187	0.1	0.1	0.298
	Abduction (°)	−1.2	0.4	0.764	−1.6	0.2	0.918	−1.2	1.2	0.748	−1.1	0.1	0.133
	Internal rotation (°)	0.5	4.0	0.637	0.7	3.7	0.662	−1.0	3.9	0.365	0.3	0.4	0.175
	Extension (°)	−9.6	14.1	0.341	−11.6	15.8	0.556	−7.9	14.2	0.112	−10.5	11.2	0.269
Range of motion	Extension (°)		6.3			3.9	0.043		1.43			−0.29	0.219
	Flexion (°)		146.1			151.6	0.119		146.9			146.1	0.638
Q–Angle (°) *1			20.6			15.3	0.104		21.1			16.4	0.015
VAS (mm) *2			57.0			22.0	0.107		42.7			23.1	0.260

*1: Quadriceps angle.
*2: Visual Analog Scale.

at full extension and 120° and the largest volume was measured at 50°. Bastiaansen-Jenniskens et al.[4] studied the association between inflammation of the IPFP and development of fibrosis. They found that production of collagen and procollagen-lysine, 2-oxoglutarate 5-dioxygenase 2 by fibroblast-like synoviocytes was 1.8-fold ($p<0.05$) and 6.0-fold ($p<0.01$) higher, respectively, in the presence of fat-conditioned medium (FCM), relative to control cultures without FCM. Therefore, there was a clear association between inflammation and occurrence of fibrosis. Paulos et al.[20, 21] concluded that "Infrapatellar contracture syndrome (IPCS)" would reduce patella mobility, especially superior patellar gliding. We reported that anterior movement of the IPFP during quasi-static knee extension decreased significantly in KOA patients relative to young, healthy subjects. Therefore, long-lasting inflammation with fibrosis might have restricted movement of the patella as well as the IPFP in KOA patients. Kitagawa et al.[22] investigated dynamics of the IPFP using ultrasonography at deep flexion of the knee during kneeling after anterior cruciate ligament reconstruction. Those who demonstrated complete knee flexion during kneeling exhibited an increased change in thickness of the IPFP during knee flexion between 10° and 90°. The current study showed that manual release increased movement of the IPFP, which may help to restore knee mobility in KOA patients.

There were no changes in patellar distance or patellar tendon angle in the R group from 30° to 0° knee flexion at pre-intervention. After intervention, the anterior contour of the IPFP was more anteriorly positioned, while the patellar distance between the inferior pole of the patella and tibial tubercle was decreased. Therefore, manual release was effective in improving anterior movement of the IPFP toward the patellar tendon in patients with KOA. On the other hand, the S group demonstrated no changes at pre-intervention, while only the patellar tendon angle increased after intervention without changing the patellar distance or IPFP position. Although the R group failed to experience diminished pain or ROM, compared with the S group, greater IPFP mobility may benefit other physical parameters, such as kneeling angle[22]. We have reported that the IPFP moved anteriorly and patellar tendon angle increased during QSKE in young, healthy people[17]. Therefore, the IPFP in KOA patients was more like that of young, healthy people after manual release. Kim et al.[23] reported that the patella-patellar tendon angle was smaller in patients with IPFP syndrome (137.3 ± 4.9° (± SD)) than in people without knee pathology (141.4 ± 2.9°) ($p<0.001$). Assuming that the control group has better knee function, we speculate that improving mobility of the IPFP in patients with KOA may help to achieve better knee function.

We utilized previously validated methods[17]. 3D models were created by manual segmentation using MRI images taken at a slice pitch of 1 mm. We superimposed 3D models created for two knee positions and analyzed the differences. Subjects in the KOA group were recruited from patients diagnosed as having KOA with a KL grade of 1 to 4, based on X-ray examinations by orthopedic surgeons at our hospital. Therefore, the generalizability of this study is limited to patients with KOA. This study is the first to investigate effects of manual therapy to improve IPFP mobility during QSKE in KOA patients. Further studies assessing movement and volume of the IPFP and clinical symptoms are needed to determine the degree of benefit that KOA patients may derive from manual therapy.

There were four limitations in this study. First, the small sample size may have introduced beta errors with a post-hoc power of 0.32 utilizing an alpha value of 0.05 and means and standard deviations derived from movement of the IPFP. Second, when segmenting the IPFP using MRI, it is sometimes difficult to determine the exact contour of the IPFP, particularly on the sides and posterior contours. Therefore, we should analyze the volume of the IPFP in lateral, medial, and/or posterior hyperoctants. Third, knee positions at 30° and 0° during MRI scanning were determined using a goniometer, which may also have introduced some error. Fourth, we treated KOA patients using several methods, for example, manual therapy, stretching, training exercise, and icing. Therefore, our results were influenced by combined therapeutic strategies. We cannot conclude that any single treatment method was most effective. Despite the above limitations, there were no apparent sources of bias that would invalidate the conclusions.

IPFP movement, patellar distance and patellar tendon angle in KOA patients during quasi-static knee extension can be improved by the manual release technique. These results should help clinicians to treat patient knees to optimize IPFP movement. In the future, it would be useful to investigate more effective therapeutic methods and their effects on knee function and patient outcomes.

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