

Morphological Changes in the Infrapatellar Fat Pad During Walking Detected by Dynamic Ultrasound in Healthy Volunteers

Review began 07/03/2024

Review ended 08/04/2024

Published 08/12/2024

© Copyright 2024

Okinaka et al. This is an open access article distributed under the terms of the Creative Commons Attribution License CC-BY 4.0., which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

DOI: 10.7759/cureus.66738

Riko Okinaka ¹, Yosuke Ishii ¹, Yuko Nakashima ², Saeko Okamoto ¹, Takato Hashizume ¹, Kexin Zhu ¹, Chen Xu ¹, Yoshitaka Iwamoto ³, Nobuo Adachi ⁴, Makoto Takahashi ¹

1. Department of Biomechanics, Graduate School of Biomedical and Health Sciences, Hiroshima University, Hiroshima, JPN 2. Department of Orthopaedic Surgery, Chugoku Rosai Hospital, Hiroshima, JPN 3. Department of Clinical Practice and Support, Hiroshima University Hospital, Hiroshima, JPN 4. Department of Orthopaedic Surgery, Graduate School of Biomedical and Health Sciences, Hiroshima University, Hiroshima, JPN

Corresponding author: Yosuke Ishii, yishii77@hiroshima-u.ac.jp

Abstract

Aim

This study aimed to verify specific morphological changes in the infrapatellar fat pad (IFP) during walking in healthy young participants.

Methods

A total of 17 healthy young participants (mean age, 22.8 ± 0.9 years) were recruited in this cross-sectional study. The IFP was evaluated using ultrasonography in three conditions: supine, standing, and walking. The IFP value was described as the thickness of the distal section of the IFP. Additionally, in the walking condition, the IFP was captured in video mode on ultrasonography, and its dynamics were recorded. The waveform of the IFP was produced using the sequence of the IFP thickness on each image. The morphological change of IFP (Δ IFP) was calculated in the IFP waveform and was shown as the difference in IFP thickness between the maximum and minimum at the beginning of the early stance phase. Moreover, kinematics and kinetic data were evaluated using a three-dimensional motion system, and the knee flexion angle (KFA) and knee flexion moment (KFM) were obtained.

Results

The thickness of the IFP during walking was significantly greater than that during the supine and standing conditions ($p < 0.001$ for both). The IFP waveform during walking showed a gradual increase during the stance phase and a decrease during the swing phase of the gait cycle. Δ IFP was 1.35 ± 0.42 mm and significantly correlated with the KFM ($r = 0.59$, $p = 0.007$).

Conclusions

Dynamic ultrasonography revealed a specific morphological change in the IFP during walking, which correlated with the KFM.

Categories: Physical Medicine & Rehabilitation

Keywords: knee, walking, dynamic ultrasonography, knee flexion moment, infrapatellar fat pad

Introduction

Knee osteoarthritis (OA) is a degenerative disease that causes knee pain during walking and interferes with daily activities [1,2]. Knee pain is believed to occur due to a pathological change in the knee structure that underlies mechanical stress.

The infrapatellar fat pad (IFP) within the knee joint is located between the femur, tibia, patella, and patellar tendon [3-5]. It fills the space between the patellar tendon and the tibia and moves to the posterior part of the patella with an increasing knee flexion angle (KFA). It moves anteriorly and downward with extension [3,6-8]. This flexible morphological change during joint motion plays a buffering role in the patellofemoral joint [9,10]. However, it has been shown that a decrease in the flexibility of IFP due to scarring and adhesions associated with degeneration is associated with pain [3,8,11,12]. Thus, the evaluation of the morphological change of IFP is essential for understanding knee OA pathology.

The IFP is generally evaluated using magnetic resonance imaging (MRI) [6,13]. MRI can demonstrate IFP in detail due to its ability to evaluate structures in three dimensions. However, the dynamic IFP during motion cannot be demonstrated. Ultrasonography can easily evaluate the IFP compared with MRI. The IFP is

How to cite this article

Okinaka R, Ishii Y, Nakashima Y, et al. (August 12, 2024) Morphological Changes in the Infrapatellar Fat Pad During Walking Detected by Dynamic Ultrasound in Healthy Volunteers. Cureus 16(8): e66738. DOI 10.7759/cureus.66738

evaluated in a static state owing to the limitations of the measurement equipment, and its dynamics during walking are unknown. Currently, the internal knee structure is evaluated during walking using ultrasonography. In particular, dynamic ultrasonography can detect morphological changes in the meniscus of the knee in compartments and provide insight into knee OA [14]. It would be possible to evaluate the morphological changes in the IFP during walking using a specific transducer. It has been suggested that the morphological change in the IFP depends on a joint load [13,15,16]. The external knee flexion moment (KFM) is generated as a joint load during walking and increases the patellofemoral load [17]. Therefore, it is important to understand the morphological change of the IFP during walking that causes joint loads, such as the KFM.

It is necessary to understand the dynamics of normal IFP in healthy participants to examine the dynamic IFP in OA in the future. Therefore, this study aimed to verify whether specific morphological changes in the IFP could be evaluated during walking in healthy young participants. We hypothesized that dynamic ultrasonographic evaluation can depict the IFP during walking and that morphological changes in the IFP are different than in the static state and correlated with KFM.

Materials And Methods

Participants

A total of 20 healthy young participants were recruited (mean age, 22.8 ± 0.9 years; body mass index, 21.4 ± 2.3 kg/m²; female, $n = 12$). The exclusion criteria were a history of surgical treatment of the knee, trauma to the lower extremities, and neurological disorders. This study was approved by the Ethical Committee for Epidemiology of Hiroshima University (E2021-2498-02). All participants provided informed consent to participate in this study.

Motion analysis

Kinematics and kinetic data during gait were captured using a 16-camera motion analysis system (Vicon Motion Systems, Oxford, United Kingdom) at a frequency of 100 Hz combined with eight force plates (AMTI, Watertown, Massachusetts) at a sampling frequency of 1,000 Hz. In this study, a Vicon Plug-In-Gait lower-body model was adopted, and 16 passive reflective markers were placed on the landmarks of each participant's body. The examiner first determined the axes of each participant's joints in a static position, after which the participants were instructed to walk 5 m three times at a comfortable speed. Data analyses were performed using MATLAB R 2020a (MathWorks, Natick, Massachusetts). The analysis consisted of a single gait cycle. A single-stance phase was defined as the cycle between heel contact and toe-off, and a single-swing phase was defined as the cycle between toe-off and the next heel contact. These events were defined using a 20 N threshold on the vertical ground reaction force (GRF). A single gait cycle was normalized to 100 data points. KFA, KFM, GRF, and gait speed were calculated. The flexion angle during the gait cycle exhibited a bi-peak. The first peak was the maximum value during the stance phase, and the minimum value was set at the time of heel contact. The difference between the maximum and minimum values was defined as the range of the KFA (Figure 1A). The peak of the KFM during the stance phase was the maximum value (KFMmax), and the KFM impulse was calculated as the integral of the stance phase of the KFM (Figure 1B). KFM was normalized to body weight to account for morphological differences among participants.

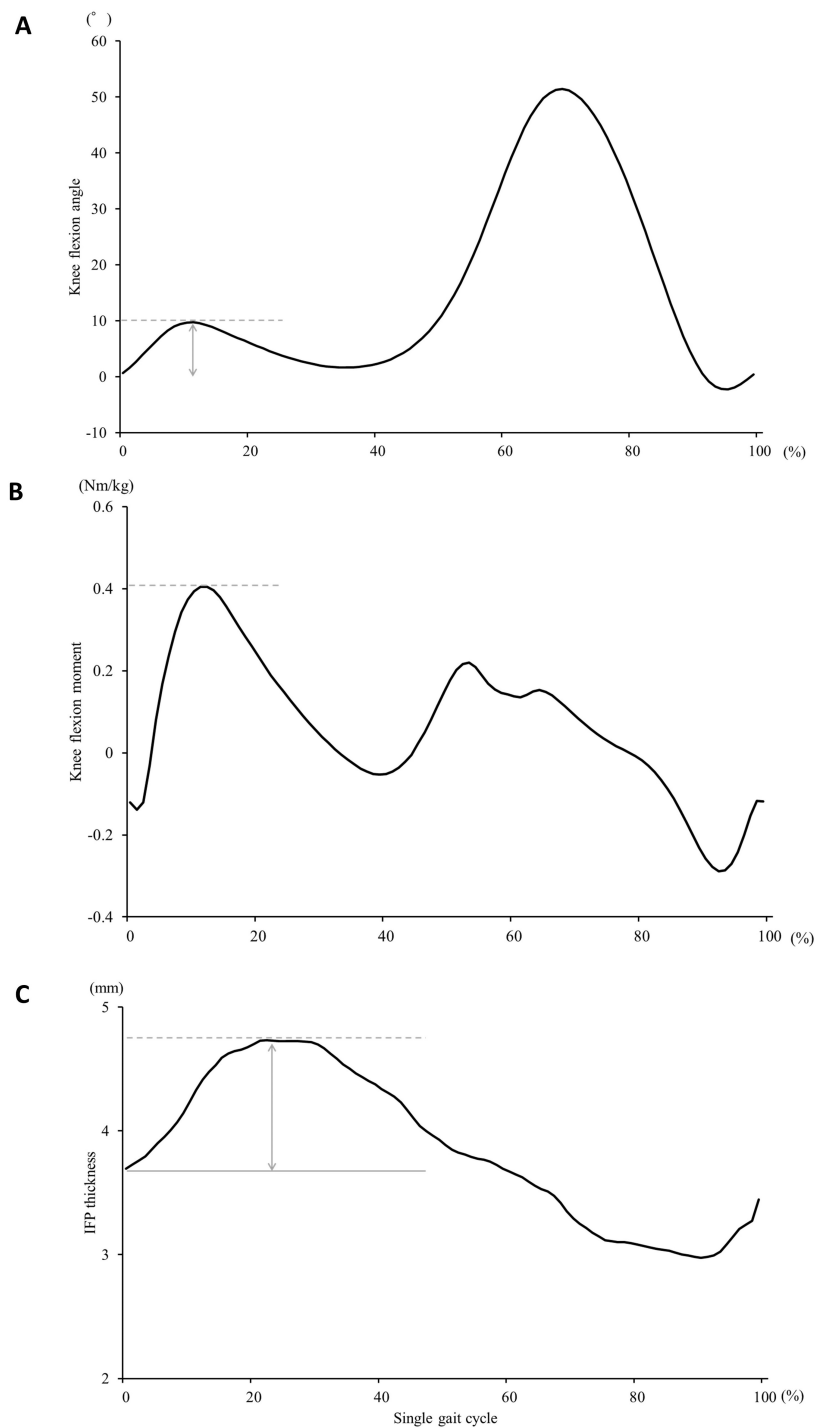


FIGURE 1: Data during one gait cycle

(A) Waveform of the knee flexion angle. The waveform shows the average of all participants (dashed line, first peaks during the stance phase; arrow, the range of the knee flexion angle); (B) waveform of the knee flexion moment. The waveform shows the average of all participants (dashed line, maximum value); (C) waveform of the infrapatellar fat pad (IFP) thickness. The waveform shows the average of all participants. Line, minimum value; dashed line, maximum value; arrow, range of IFP thickness change.

Evaluation of the IFP thickness

The IFP was taken under walking and static conditions. Static condition was supine and standing with full knee extension. Ultrasound imaging of the IFP during each task was performed using an ultrasound device (SNI BLE, KONICA MINOLTA, Tokyo, Japan) with a prototype 3-11 MHz special linear-array transducer (KONICA MINOLTA, Tokyo, Japan) without special manipulation of gain operation. The focus area on the image was adjusted to be depicted clearly. A longitudinal transducer was fitted to the anterior surface of the

knee along the patellar tendon (Figure 2A). The IFP thickness was measured using the Kinovea software (v0.8.15; Kinovea open-source project, <https://www.kinovea.org>) (Bordeaux, France). It was made with a vertical line to the undersurface of the patellar tendon, extending from the tendon to a tibial cortex point 10 mm proximal to the tendon insertion, according to a previous study (Figure 2B) [15].

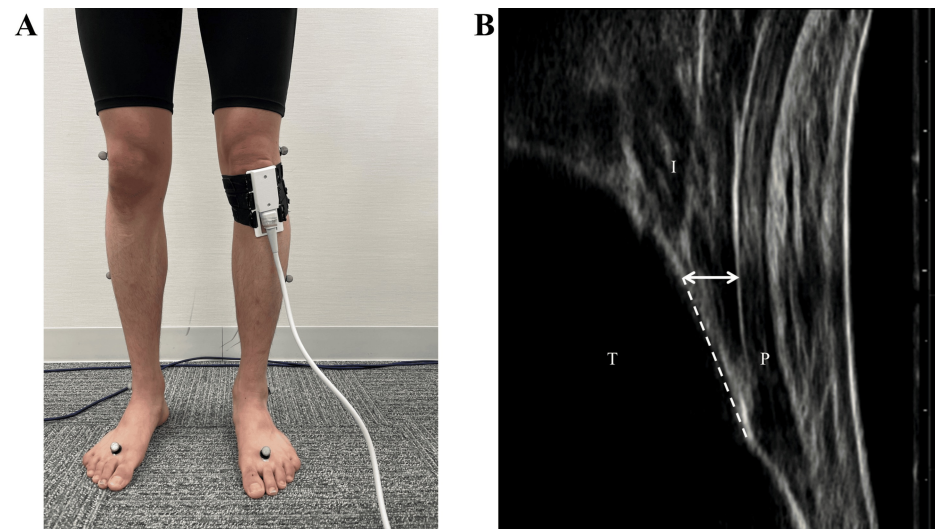


FIGURE 2: Transducer and ultrasound images

(A) Snapshot of a transducer fitted to the anterior surface of the knee; (B) ultrasound image of the infrapatellar fat pad.

I: infrapatellar fat pad; T: tibia; P: patellar tendon; dashed line: 10 mm line on a tibial cortex from the tendon insertion; arrow, IFP thickness.

In the walking condition, the participants walked with a transducer fixed to a belt. The ultrasound was performed acquired at a frequency of 30 Hz. The motion analysis system and ultrasound were temporally synchronized by an external electrical signal, and the starting time between these devices was determined. Approximately 30 ultrasound images were acquired during each gait cycle. The dates were normalized to 100 data points. The maximum value during a single gait cycle (IFPmax) was calculated, and the minimum value (IFPmin) was calculated in the range from the start of the analysis to IFPmax. The difference between the IFPmax and the IFPmin was defined as the morphological change of IFP (Δ IFP) (Figure 1C). To evaluate the reliability of IFP thickness, intra- and inter-rater reliabilities were analyzed using the intraclass correlation coefficient (ICC). Two examiners obtained additional data twice from eight participants. One examiner (R.O.) obtained ICC (1,3), and ICC (2,3) was obtained by two examiners, R.O. and Y.I., who were blinded to the participant's information.

Under static conditions, the transducer was fixed by the examiner's hands to adjust for the appropriate images. This measurement was demonstrated in supine and standing positions, with full knee extension.

Statistical analysis

For all data, the average of three trials was used for the statistical analysis, which was performed using IBM SPSS Statistics for Windows, Version 23 (Released 2015; IBM Corp., Armonk, New York). Variables were tested for normality using the Shapiro-Wilk test. The IFP thickness data were compared among the three conditions using repeated-measures analysis of variance with post-hoc Bonferroni correction. In this comparison, the IFPmax was used for the walking condition. Pearson's correlation analysis was performed to investigate the correlations between the three conditions. In addition, Pearson or Spearman correlation analysis was performed to investigate the correlation between the IFP thickness data and kinematic and kinetic data. The level of significance was set at $p < 0.05$.

To detect the correlation between the Δ IFP and KFM in the current sample size, the post-hoc test as power analysis was performed by G-power and showed that the statistical power was 86.2%.

Results

Comparison of the IFP thickness among conditions

No significant differences were observed between the IFP thickness of supine and standing conditions. The maximum value during the dynamic condition was significantly increased compared with the IFP thickness

in the supine and standing conditions (p < 0.001 for both) (Figure 3).

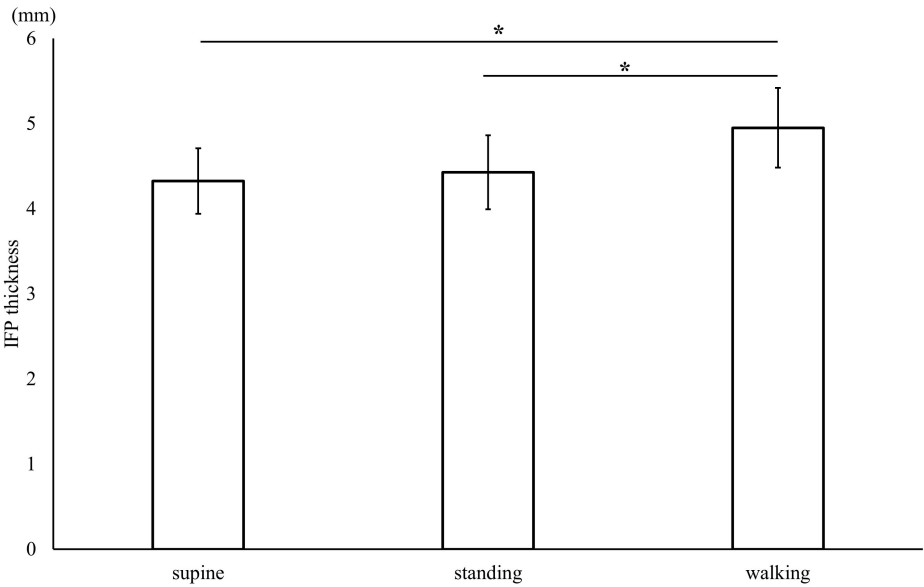


FIGURE 3: Comparison of the infrapatellar fat pad (IFP) thickness under three conditions
*shows significant differences between conditions (p < 0.01). Values represent means ± standard deviations.

In addition, the IFP thickness in the supine condition was significantly correlated with that in the standing condition (r = 0.63, p = 0.003). IFPmax during walking was also significantly correlated with IFP thickness in the supine condition (p = 0.01) and the standing condition (p < 0.01). However, ΔIFP of the dynamic condition was not correlated with the IFP thickness in the supine and standing conditions (Table 1).

	Supine		Standing	
	r	p	r	p
IFPmax	0.55	0.013	0.81	0.01
ΔIFP	0.11	0.646	0.22	0.363

TABLE 1: Correlation between three conditions

The r values represent the correlation coefficients of the infrapatellar fat pad (IFP) thickness during the dynamic condition with supine and standing conditions. IFPmax, the maximum value of the IFP thickness change during walking; ΔIFP, the range of the IFP thickness change during walking.

Evaluation of the IFP thickness during the walking conditions

Figure 1C shows an average of the IFP thickness during a single gait cycle. The maximum value occurred during the first half of the stance phase. The IFPmax was 4.95 ± 0.47 mm, the IFPmin was 3.60 ± 0.52 mm, and the ΔIFP was 1.35 ± 0.42 mm. The IFPmax was shown at approximately 21% of a single gait cycle. The KFM reached a maximum value of approximately 10%, corresponding to IFPmax immediately afterward (Figure 1BC). IFP thickness decreased with increasing KFA during the swing phase (Figure 1AC).

Reliability of measurement of the IFP thickness

ICC (1,3) and ICC (2,3) were 0.942 and 0.890, respectively, in terms of the maximum IFP thickness during walking. ICC (1,3) and ICC (2,3) were 0.930 and 0.737, respectively, in terms of the minimum IFP thickness during gait. ICC (1,3) and ICC (2,3) were 0.857 and 0.602, respectively, in terms of ΔIFP.

Kinetics and kinematics data and gait speed

Figure 1A shows an average of the KFA. The KFAMax was 9.94 ± 5.05°, the KFAMin was 0.28 ± 3.96°, the

range of KFA was 9.66 ± 3.17°. Figure 1B shows an average of the KFM. The KFMmax and the KFM impulse were 0.44 ± 0.22 Nm/kg and 0.09 ± 0.08 Nm · s/kg. The first and second peaks of GRF were 605.28 ± 110.55 N and 638.83 ± 96.34 N. The gait speed was 1.02 ± 0.14 m/s.

Correlation between the IFP thickness and biomechanical data of the walking condition

ΔIFP was significantly correlated with the KFMmax (r = 0.59, p = 0.007) (Table 2). However, ΔIFP was not correlated with the maximum value and the range of the KFA.

Table with 9 columns: Variables, KFMmax (r, p), KFM Impulse (r, p), KFAMax (r, p), and Range of KFA (r, p). Rows include IFPmax and ΔIFP.

TABLE 2: Correlation between the IFP thickness and biomechanical data during walking

The r values represent the correlation coefficients. IFPmax, the maximum value of the infrapatellar fat pad (IFP) thickness change; ΔIFP, the morphological change of the IFP; KFMmax, the maximum value of the knee flexion moment; KFM impulse, the integral of the stance phase of the knee flexion moment; KFAMax, the first peak of the knee flexion angle during the stance phase; Range of KFA, the range of the knee flexion angle during the stance phase.

Discussion

To the best of our knowledge, this is the first study to evaluate the IFP during walking using ultrasonography, which showed a unique waveform. The IFPmax on the waveform was observed in the first half of the stance phase, and KFMmax was significantly correlated with ΔIFP, supporting our hypothesis.

The IFPmax in the walking condition was significantly greater than those in the supine and standing conditions. The IFP moves anteriorly and downward when the knee joint is extended [3,6–8]. Since the knee joint was fully extended in the supine and standing conditions but flexed during walking, the IFP thickness was expected to be thicker in both the supine and standing conditions than in the walking condition. However, the IFPmax in the walking condition was thicker than that in either of the other two conditions, suggesting that conventional evaluation methods may underestimate the dynamics of the IFP according to mechanical stress. Previous studies have compared the IFP only under static conditions [7,11,13,15], although knee pain occurs under mechanical stress during daily activities such as walking. Therefore, this study suggests the necessity to evaluate under not only static conditions but also dynamic conditions during walking. Moreover, the morphological changes in the IFP during walking did not correlate with the thickness of the IFP observed in the supine and standing conditions. Therefore, the morphological change in the IFP during walking is a unique factor that could provide insights for understanding the structural reaction under mechanical stress.

In general, the IFP thickness decreases with increased KFA [13]. However, IFP thickness increased during the early stance phase when the KFA increased. Previous studies have reported that the patellar tendon straightens and the IFP thickness increases because of quadriceps muscle contraction [15]. It is inferred that the quadriceps muscle contraction related to KFM contributes to morphological change in the IFP during the first half of the stance phase. The maximum IFP thickness during walking was observed in the first half of the stance phase. The loading response in the first half of the stance phase was one of the highest-load phases. It has been reported that shock-absorbing properties are required [17]. In this study, the KFMmax was observed during the loading response, and the IFP thickness was observed at its maximum value immediately after the KFMmax, indicating a significant correlation between the KFMmax and ΔIFP. Furthermore, the patellofemoral joint stress calculated from the joint moments was high during the loading response [18,19]. The patellofemoral joint stress is believed to increase because the KFM increases during the loading response. The dynamic IFP during the stance phase would be related to the joint load and quadriceps contraction rather than to the KFA. In healthy young participants, morphological changes in the IFP may reduce the load during walking.

Our data revealed a unique waveform of IFP thickness during walking that differed from the IFP parameters, which were evaluated only in the static state [11,13]. Moreover, dynamic evaluation demonstrated good reliability. These results indicate that dynamic ultrasound is a clinical tool for detecting morphological changes in the IFP associated with IFP dysfunction under mechanical stress. In the future, evaluation of the IFP during walking in patients with OA may provide information to determine whether the buffering effect is functioning as compared to healthy participants. The causes of OA pain differ among individuals [20]. Particularly, the poor morphological change of IFP is often observed in symptomatic knee patients

under weight-bearing situations whereas the mechanism is still unknown. Evaluating the IFP during walking may be the first step to describe the symptomatic knee OA and contribute to the elucidation of the pathophysiology of clinical problems in patients with knee OA.

This study had several limitations. First, evaluating the IFP may have been influenced by muscle contraction even in the static state. Particularly, the patellar tendon tension, which depends on quadriceps muscle contraction, affects the IFP thickness in a static state [15]. Moreover, muscle contraction is easy to change under a variety of positions and joint angles. These could emphasize the evaluation of muscle activity according to the IFP morphological change and affect the directory of our findings. Second, we could not determine how muscle activity during walking affected the IFP. The change in the IFP thickness during walking is believed to be related to quadriceps muscle contraction; however, we were unable to examine this effect in this study. Therefore, it is necessary to examine the muscle activity in the future. Third, this study could not evaluate the entire IFP. Only the distal portion of IFP was evaluated in this study because of technical limitations in using the ultrasound device. However, a previous study showed that the change in the IFP is greater in the distal portion rather than in the proximal portion [21]. Therefore, the distal portion of IFP was considered to contribute to elaborating the mechanism of IFP movement. Fourth, our data did not obtain quality data on IFP such as fibrosis situations, so it remains unclear whether it affects the morphological change. However, healthy young subjects were recruited in this study, so it might have minimized the effect of IFP fibrosis on the morphological change. However, further studies are required to determine the quality of the IFP information and muscle activity.

Conclusions

This study was demonstrated to evaluate the IFP during walking using ultrasonography. Dynamic ultrasonography revealed a specific morphological change in the IFP associated with the KFM during walking. This data could contribute to understanding the elucidation of the pathophysiology of clinical problems in patients with knee OA.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Riko Okinaka, Yosuke Ishii, Yuko Nakashima

Acquisition, analysis, or interpretation of data: Riko Okinaka, Saeko Okamoto, Takato Hashizume, Xexin Zhu, Chen Xu, Nobuo Adachi, Makoto Takahashi, Yoshitaka Iwamoto

Drafting of the manuscript: Riko Okinaka, Yosuke Ishii

Supervision: Yosuke Ishii, Makoto Takahashi

Critical review of the manuscript for important intellectual content: Yuko Nakashima, Saeko Okamoto, Takato Hashizume, Xexin Zhu, Chen Xu, Nobuo Adachi, Makoto Takahashi, Yoshitaka Iwamoto

Disclosures

Human subjects: Consent was obtained or waived by all participants in this study. Ethical Committee for Epidemiology of Hiroshima University issued approval E-2498-2. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later versions. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** This study was supported by Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (JSPS) (Award Number: 21K111915) and the Konica Minolta Science and Technology Foundation. **Financial relationships:** Yosuke Ishii, Yuko Nakashima declare(s) receipt of equipment from KONICA MINOLTA, INC. Yosuke Ishii and Yuko Nakashima declare that they have the lendable device of ultrasound from KONICA MINOLTA, INC. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

References

1. Cross M, Smith E, Hoy D, et al.: The global burden of hip and knee osteoarthritis: estimates from the Global Burden of Disease 2010 study. *Ann Rheum Dis*. 2014, 73:1323-30. [10.1136/annrheumdis-2013-204763](https://doi.org/10.1136/annrheumdis-2013-204763)
2. Zhang W, Nuki G, Moskowitz RW, et al.: OARS recommendations for the management of hip and knee osteoarthritis: part III: changes in evidence following systematic cumulative update of research published through January 2009. *Osteoarthritis Cartilage*. 2010, 18:476-99. [10.1016/j.joca.2010.01.013](https://doi.org/10.1016/j.joca.2010.01.013)
3. Dragoo JL, Johnson C, McConnell J: Evaluation and treatment of disorders of the infrapatellar fat pad .

- Sports Med. 2012, 42:51-67. [10.2165/11595680-000000000-00000](#)
4. Eymard F, Chevalier X: Inflammation of the infrapatellar fat pad. *Joint Bone Spine*. 2016, 83:389-93. [10.1016/j.jbspin.2016.02.016](#)
 5. Edama M, Otsuki T, Yokota H, Hirabayashi R, Sekine C, Maruyama S, Kageyama I: Morphological characteristics of the infrapatellar fat pad. *Sci Rep*. 2022, 12:8923. [10.1038/s41598-022-12859-1](#)
 6. Stephen JM, Sopher R, Tullie S, Amis AA, Ball S, Williams A: The infrapatellar fat pad is a dynamic and mobile structure, which deforms during knee motion, and has proximal extensions which wrap around the patella. *Knee Surg Sports Traumatol Arthrosc*. 2018, 26:3515-24. [10.1007/s00167-018-4943-1](#)
 7. Kitagawa T, Nakase J, Takata Y, Shimozaki K, Asai K, Tsuchiya H: Use of ultrasonography to evaluate the dynamics of the infrapatellar fat pad after anterior cruciate ligament reconstruction: a feasibility study. *J Med Ultrason* (2001). 2019, 46:147-51. [10.1007/s10396-018-0917-7](#)
 8. Cowan SM, Hart HF, Warden SJ, Crossley KM: Infrapatellar fat pad volume is greater in individuals with patellofemoral joint osteoarthritis and associated with pain. *Rheumatol Int*. 2015, 35:1439-42. [10.1007/s00296-015-3250-0](#)
 9. Fontanella CG, Belluzzi E, Pozzuoli A, Favero M, Ruggieri P, Macchi V, Carniel EL: Mechanical behavior of infrapatellar fat pad of patients affected by osteoarthritis. *J Biomech*. 2022, 131:110931. [10.1016/j.jbiomech.2021.110931](#)
 10. Fontanella CG, Carniel EL, Frigo A, et al.: Investigation of biomechanical response of Hoffa's fat pad and comparative characterization. *J Mech Behav Biomed Mater*. 2017, 67:1-9. [10.1016/j.jmbbm.2016.11.024](#)
 11. Kitagawa T, Nakase J, Takata Y, et al.: Flexibility of infrapatellar fat pad affecting anterior knee pain 6 months after anterior cruciate ligament reconstruction with hamstring autograft. *Sci Rep*. 2020, 10:21347. [10.1038/s41598-020-78406-y](#)
 12. Shiraishi R, Ueda S: Relationship between the change in infrapatellar fat pad thickness assessed using ultrasonography and anterior knee pain on squatting after anterior cruciate ligament reconstruction. *J Med Ultrason* (2001). 2023, 50:237-43. [10.1007/s10396-023-01300-3](#)
 13. Dragoo JL, Phillips C, Schmidt JD, Scanlan SF, Blazek K, Steadman JR, Williams A: Mechanics of the anterior interval of the knee using open dynamic MRI. *Clin Biomech* (Bristol, Avon). 2010, 25:433-7. [10.1016/j.clinbiomech.2010.01.011](#)
 14. Ishii Y, Ishikawa M, Nakashima Y, et al.: Knee adduction moment is correlated with the increase in medial meniscus extrusion by dynamic ultrasound in knee osteoarthritis. *Knee*. 2022, 38:82-90. [10.1016/j.knee.2022.07.011](#)
 15. Naredo E, Canoso JJ, Yinh J, et al.: Dynamic changes in the infrapatellar knee structures with quadriceps muscle contraction. An in vivo study. *Ann Anat*. 2021, 235:151663. [10.1016/j.aanat.2020.151663](#)
 16. Bohnsack M, Hurschler C, Demirtas T, Rühmann O, Stukenborg-Colsman C, Wirth CJ: Infrapatellar fat pad pressure and volume changes of the anterior compartment during knee motion: possible clinical consequences to the anterior knee pain syndrome. *Knee Surg Sports Traumatol Arthrosc*. 2005, 13:135-41. [10.1007/s00167-004-0561-1](#)
 17. Astephen JL, Deluzio KJ: Changes in frontal plane dynamics and the loading response phase of the gait cycle are characteristic of severe knee osteoarthritis application of a multidimensional analysis technique. *Clin Biomech* (Bristol, Avon). 2005, 20:209-17. [10.1016/j.clinbiomech.2004.09.007](#)
 18. Ho KY, Blanchette MG, Powers CM: The influence of heel height on patellofemoral joint kinetics during walking. *Gait Posture*. 2012, 36:271-5. [10.1016/j.gaitpost.2012.03.008](#)
 19. Heino Brechter J, Powers CM: Patellofemoral stress during walking in persons with and without patellofemoral pain. *Med Sci Sports Exerc*. 2002, 34:1582-93. [10.1097/00005768-200210000-00009](#)
 20. Giorgino R, Albano D, Fusco S, Peretti GM, Mangiavini L, Messina C: Knee osteoarthritis: epidemiology, pathogenesis, and mesenchymal stem cells: what else is new? An update. *Int J Mol Sci*. 2023, 24:6405. [10.3390/ijms24076405](#)
 21. Okita Y, Oba H, Miura R, Morimoto M, Gamada K: Movement and volume of infrapatellar fat pad and knee kinematics during quasi-static knee extension at 30 and 0° flexion in young healthy individuals. *Knee*. 2020, 27:71-80. [10.1016/j.knee.2019.10.019](#)