Journal of the Anatomical Society of India 66 (2017) 83–90

Contents lists available at ScienceDirect

Journal of the Anatomical Society of India

journal homepage: www.elsevier.com/locate/jasi

Original Article

Patterns of patellofemoral articular cartilage wear in Japanese cadavers

Tomonori Sato[a,*], Naomi Sato[b], Takeshi Sasaki[c], Kohji Sato[c], Gerard C. Gorniak[d]

[a] Department of Physical Therapy, Tokoha University, Shizuoka, Japan
[b] Department of Nursing, Hamamatsu University School of Medicine, Hamamatsu, Japan
[c] Department of Anatomy & Neuroscience, Hamamatsu University School of Medicine, Hamamatsu, Japan
[d] Institute of Physical Therapy, University of St. Augustine for Health Sciences, United States

ARTICLE INFO

Article history:
Received 30 August 2016
Accepted 25 November 2017
Available online 26 November 2017

Keywords:
Cartilage
Knee
Patella
Patellofemoral joint

ABSTRACT

Introduction: Although we recently reported a detailed description of wear pattern in Caucasians, few studies have investigated severity of wear, and pattern of wear on the patella and femur in Japanese. The purpose of this study was to determine if there is a common joint specific wear pattern in the patellofemoral joint of Japanese cadavers. We further compared the wear pattern and severity between Japanese and US cadavers.
Methods: We examined 46 patellae and matching femurs from 23 Japanese cadavers. The wear location was transcribed to gridded templates, that were compared for frequency, gender, and sidedness of wear.
Results: Over 60% of the patella showed wear in the odd facet, the middle part of the medial facet, and the medial aspect of the middle part of the lateral facet. The distal femur showed common areas of wear in the posterior aspect of the medial femoral condyle and anterior aspect of the medial femoral condyle. Patella wear may differ with gender as male's wear was more compact. Although the patella and femur wear area was similar between Japanese and US cadavers, femoral wear may be more severe in Japanese cadavers.
Discussion: Patella and femur showed distinct regions of articular cartilage wear. The wear patterns and locations suggest that wear occurs mainly when the knees are moderately and deeply flexed and that these wear patterns may result from common traditional Japanese style of knee positions or activities.

1. Introduction

Osteoarthritis of the knee (knee OA) is a major public health issue that impairs daily lives.[1,2] The number of patients with knee OA is suggested to be increasing with advancing age of the Japanese population.[3] According to the National Livelihood Survey of the Ministry of Health, Labour and Welfare in Japan, OA is now ranked second among the diseases that cause disabilities requiring support with their daily living activities .[4]

Two of the most common forms of knee OA are combined tibiofemoral and patellofemoral OA, followed by patellofemoral OA.[5,6] Thus, the patellofemoral joint is a very common site for knee OA [7] and it can frequently occur in the absence of tibiofemoral joint OA.[6,8] In addition, patellofemoral OA is believed to develop prior to tibiofemoral OA.[9]

The patellofemoral joint is exposed to forces ranging from 0.5 to 9.7 times body weight during daily activity.[10] Such considerable force, altered stress due to abnormal alignment, and repetitive movement may result in a specific and common wear pattern of the articular cartilage.[11]

Although numerous studies have focused on patellofemoral joint kinematics, articular contact forces, articular contact areas, and cartilage thickness of the patellofemoral joint,[12–14] a limited number of studies have performed extensive macroscopic studies on wear area, severity, and pattern of the patellofemoral joint. We recently reported a detailed description on the location, and severity of wear, gender, and side differences, and specific pattern of wear on the patella and femur in Caucasians.[11] In that study, the articular surface of the patella showed more wear in the horizontal area. The distal femur showed common wear in the posterior aspect of the medial, posterior aspect of lateral femoral condyles, and anterior aspect of the medial femoral condyle.

Understanding the anatomy of the patellofemoral joint is a prerequisite to successful management of patients with patellofemoral pathology. In this study, the patellofemoral joints of female and male Japanese cadavers were examined bilaterally. The purpose of this study was to determine if there is a common joint specific wear pattern in the patellofemoral joint of Japanese

* Corresponding author: Department of Physical Therapy, Tokoha University 1-30 Mizuochi, Aoiku 420-0831, Japan. Tel: 81-54-297-3244.
E-mail address: tomo310@sz.tokoha-u.ac.jp (T. Sato).

https://doi.org/10.1016/j.jasi.2017.11.004
0003-2778/

cadavers. We further compared the wear pattern and severity between Japanese and US cadavers.

2. Methods

2.1. Specimens

Twenty-three cadavers, 11 males (age 84.9 ± 8.4 years) and 12 females (age 85.3 ± 5.9 years), randomly obtained from the anatomical board were used to map articular cartilage wear on 46 patellae and 46 distal femurs. Limbs with any noticeable trauma or recent surgery, or hip or knee prosthesis were excluded from this study. Causes of death and occupations varied and were not factors used for selection. Each cadaver received a number and the age and their gender were recorded. Each patella and distal femur was given a specimen number that coincided with the cadaver number and defined as being of the right or left side. This numbering system allowed specimen data to be matched directly to cadaver data for comparison and analysis.

2.2. Measurements

Bilateral patellofemoral joints were opened. The vertical lengths, horizontal lengths of the articular surfaces, and wear perimeters of the patella and distal femur were measured in millimeters using a caliper (Figs. 1 and 2). The vertical length of the patella was the distance measured from the inferior articular limit to the superior articular limit and the horizontal length was the distance measured from the medial articular limit to the lateral articular limit of the articular surface. The horizontal length of the femur was the distance measured from the medial articular limit of the medial condyle to the lateral articular limit of the lateral condyle of the distal femur, and the vertical length was the distance measured from the posterior articular limit of the lateral condyle to the anterior articular limit of the lateral condyle (Fig. 1).

The locations of wear were mapped on a template showing the articular surfaces of these bones. Horizontal zero was the inferior articular limit of the patella and posterior articular limit of the distal femur (Fig. 2). The following four measurements in millimeters were taken on each bone: (1) horizontal length (X1) from the medial end of bone's articular surface to the medial limit of the wear region; (2) horizontal length (X2) from the medial end of bone's articular surface to the lateral limit of the same wear region as in #1; (3) vertical length (Y1) from the inferior end of bone's articular surface to the inferior limit of the wear region in #1; (4) vertical length (Y2) from the inferior end of the bone's articular surface to the superior limit of the wear region in #1. All measurements were performed by the same person. Initially using 10 knee joints, all four measurements were blinded and repeated a week apart and then compared. The measurements differed by 1–2 mm.

After the horizontal and vertical lengths of the articular surfaces of the patella and distal femur were measured, the average size was calculated (Table 1). The horizontal and vertical lengths of these bones varied between females and males; therefore, the mapping of wear locations for the patella and distal femur had to be adjusted for these variations. To make this adjustment, the overall average horizontal length and vertical length of each bone was made equal to 100%. The template for each bone was then aligned on a percentage scale (Fig. 1). X1, X2, Y1, and Y2 positions were then re-calculated as percentages of the overall articular surface of the bone. These points were then plotted on a percentage template to obtain a distribution map of wear (Figs. 3–5).

The magnitude of wear was rated from 0 to IV with 0 = none; I = minimum (soft and swollen cartilage); II = mild (surface cracks, fissure in an area with a diameter less than 1.5 cm); III = moderate (surface cracks, fissure in an area with a diameter greater than 1.5 cm); and IV = severe (exposed subchondral bone) as has been used previously.[11,15] Rating the wear grade was performed by two people. After one rated the wear grade of each patella and femur, and another with over 35 years of experience performing cadaver dissection rated the same specimens. All wear grades were consistent between the two evaluators.

A *t*-test (two-sided) was used to compare any differences in (1) horizontal and vertical length of the articular surface of the patella and distal femur between females and males, and (2) mean wear area of the patella and femur between females and males. A *t*-test was also used to compare any differences in age and body mass index (BMI) between females and males. The level of significance was $P < 0.05$.

3. Results

3.1. Basic information

There were no significant differences in age and BMI between females and males. In the horizontal and vertical length of the patella and the femur, the measurement of males were significantly larger than for females. The horizontal length of the articular surfaces of the patella was greater than the height. The horizontal length of the articular surfaces of the femur was also greater than the height (Table 1).

3.2. Patella

The central aspect of the odd facet, middle part of the medial facet, and medial aspect of the middle part of the lateral facet showed wear on 61% of specimens for the entire right articular surface of the patella. On the left patella, 60% showed wear in the

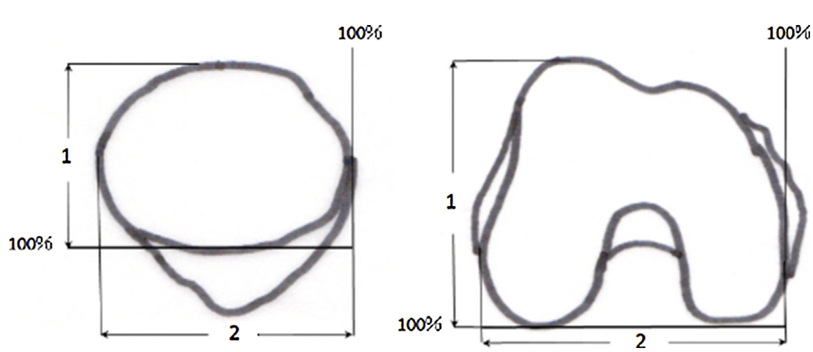

Fig. 1. Diagram illustrating the method used to measure patella and femur dimensions.
1. Vertical length of articular surfaces of each bone, 2. Horizontal length of articular surfaces of each bone.

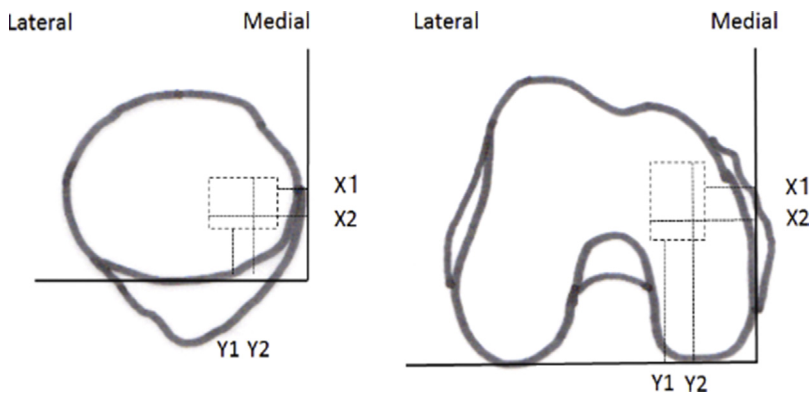

Fig. 2. Diagram illustrating the method used to measure the position and areas of wear on the patella and femur. X1: medial limit of the wear region of each bone; X2: lateral limit of the wear region; Y1: inferior limit of the wear region; Y2: superior limit of the wear region.

Table 1
Basic specimen information.

Sex	Specimen No.	Age (years)	BMI	Patella		Femur	
				Horizontal length	Vertical length	Horizontal length	Vertical length
Male	11	84.9 ± 8.3	18.8	46.2 ± 0.9 *	32.8 ± 1.3 *	76.0 ± 3.0 *	65.1 ± 2.3 *
Female	12	85.5 ± 5.9	20.0	42.3 ± 2.6 *	30.7 ± 1.4 *	68.0 ± 2.8 *	59.8 ± 2.1 *

* $P < 0.05$ comparing genders.

medial aspect of the odd facet, middle part of the medial facet and medial aspect of the middle part of the lateral facet. In addition, 70% showed wear in the lateral aspect of the middle part of the medial facet and medial aspect of the middle part of the lateral facet (Fig. 3A, B). For all of the articular surfaces in the patella examined, 77.4% of total wear areas were rated as III and IV and 22.6% were rated as grade I and II. Table 2 provides the wear ratings for the articular surfaces of the patella and femur.

Gender comparisons revealed that 58% of females had wear in the central aspect of the odd facet, middle part of the medial facet, and medial aspect of the lateral facet on the right patella (Fig. 3D). 73% of males showed wear in the central aspect of the middle part of the odd facet and middle part of the medial facet on the right patella (Fig. 3F).

On the left patella of females, 56% showed wear in the middle part of the odd facet, middle part of the medial facet and middle part of the lateral facet. 75% showed wear in the medial aspect of the middle part of the lateral facet (Fig. 3C). In the left patella of males, 64% showed wear in the lateral aspect of the odd facet, middle part of the medial facet and medial aspect of the middle part of the lateral facet. 73% showed wear in the central aspect of the middle part of the medial facet (Fig. 3E).

3.3. Distal femur

Fig. 4 shows the wear area on the distal femur. The posterior aspect of the medial femoral condyle was the most commonly observed wear area followed by the anterior aspect of the medial femoral condyle. 61% showed wear in the anterior aspect of the right medial femoral condyle and 65% showed wear in the posterior aspect of the right medial femoral condyle (Fig. 4A). On the left femur, the wear was observed in 35% of cadavers in the anterior aspect of the right medial femoral condyle and in 57% of cadavers in the posterior aspect of the medial femoral condyle (Fig. 4B). Based on the Outerbridge classification, 16.8% of the femoral wear areas were grade II or less and 83.2% were grade III or IV.

Gender comparisons showed that females and males had the same wear distribution (wear portion), however, males showed a higher percentage of wear in the anterior aspect of the right medial femoral condyle (males vs. females: 73% vs. 58%) and posterior aspect of the right medial femoral condyle (males vs. females: 73% vs. 58%) (Fig. 4C, E) and posterior aspect of the left medial femoral condyle (males vs. females: 73% vs. 50%; Fig. 4D, F).

3.4. Females vs. Males

Comparing wear patterns in males and females more clearly, the observed wear area overlapped in more than 50% of male and female cadavers. The male patellar wear patterns differed from those of females. Although both male and female patterns extended in the horizontal middle of the patella, males showed a more central and compact wear pattern (Fig. 5A, B).

The femoral wear pattern differed between females and males. Males had larger areas of wear in the anterior aspect of the medial femoral condyle and posterior aspect of the medial condyle than females (Fig. 5C, D). Furthermore, males showed wear in the posterior aspect of the lateral femoral condyle in addition to wear in the medial condyle, although females showed wear in the anterior aspect of the medial femoral condyle and posterior aspect of the medial femoral condyle. (Fig. 5C, D). However, the wear in the posterior aspect of the lateral femoral condyle was larger in the right femur of males (Fig. 5C, D).

Comparisons of total wear area between females and males showed a significantly larger wear area involving the medial facet, odd facet, and lateral facet in the right patella and femur of males (Table 3). However, the wear area of the left patella and left femur of males were not significantly larger than that of females.

4. Discussion

The horizontal and vertical lengths of the patella and femur were significantly larger in males than in females. This simply reflects that males have larger bony geometry than females, which

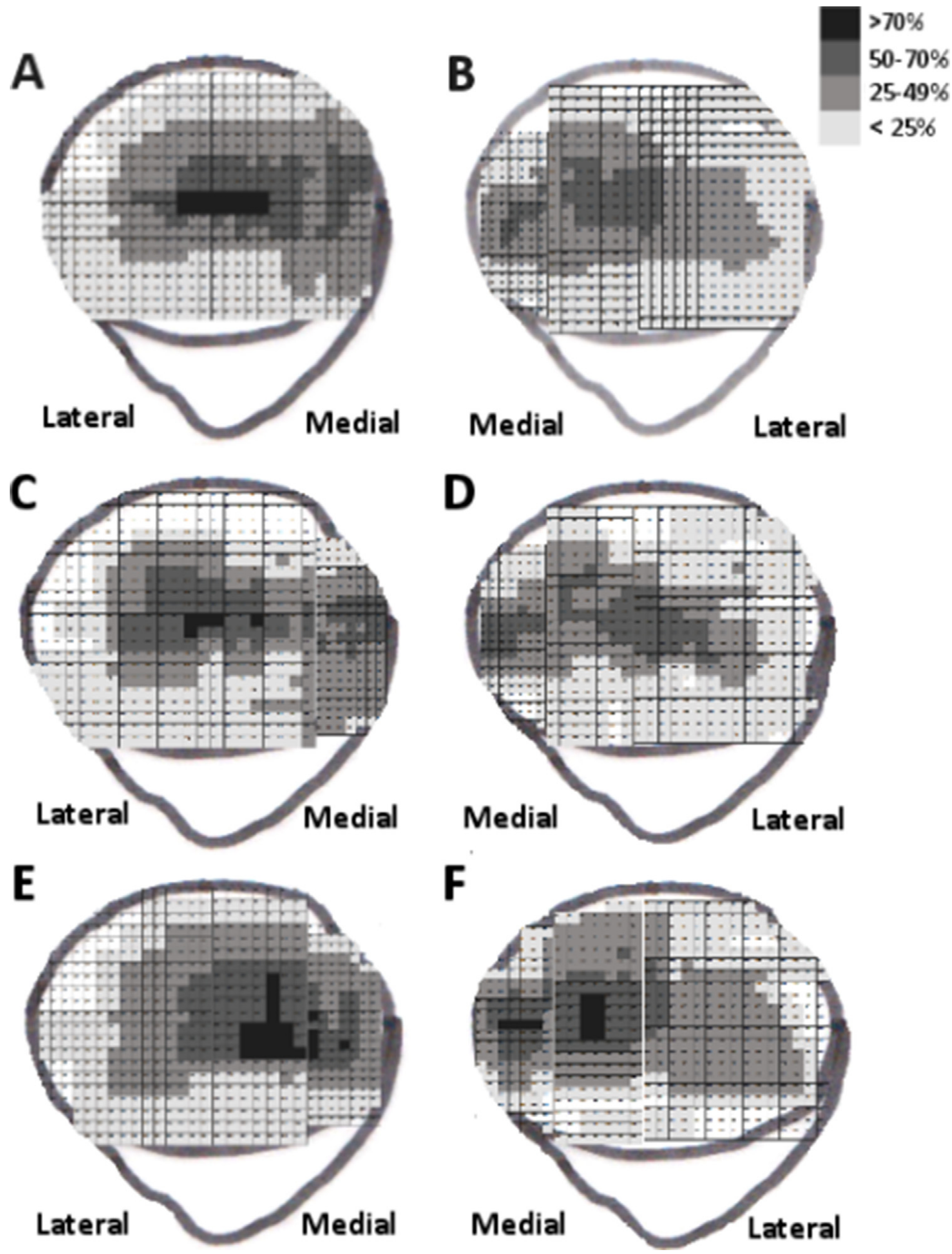

Fig. 3. Wear area and patterns of the patella. Left (A, C, E) and right patella (B, D, F). A, B: Female and male wear patterns; C, D: Female wear pattern; E, F: Male wear pattern.

is consistent with previous studies.[16,17] Similarly, the horizontal length of the articular surface of the patella and femur is greater than the vertical length, which is consistent with previous studies.[18]

4.1. Patella – general wear pattern

The common wear area on the patella was the odd facet, and the middle part of the medial facet, followed by the medial aspect of the middle part of the lateral facet. The wear of the middle part of the patella reflects the area where the knee is between 45°–90° of flexion. This is consistent with the area we usually use as range of motion during daily activities such as walking (10–20°), stair climbing (45–65°), and running (50°).[10,19] The knee flexion angle between 60°–90° is also known to cause the greatest pressure for the patellofemoral joint, ranging from 0.5 to 9.7 times body weight.[10,21]

Asian populations have been known to spend most of their lives using tatami mats, sitting cross-legged, and kneeling, which requires the knee joints to flex up to 150°.[20,21] These postures or activities requiring deep flexion of the knee causes the odd facet to contact the medial femoral condyle of the femur, which is associated with knee OA.[1,22] Therefore, these traditional daily postures or activities may contribute to the development of common wear of the odd facet.

Epidemiologic studies have reported that medial knee OA is more common than lateral OA.[23,24] In such a medial knee OA, the causative effect of decreased Q-angle on the progression of knee OA has been reported.[27,28] Decreased Q-angle also causes a medial shift of the contact area with peak pressure on the medial facet and

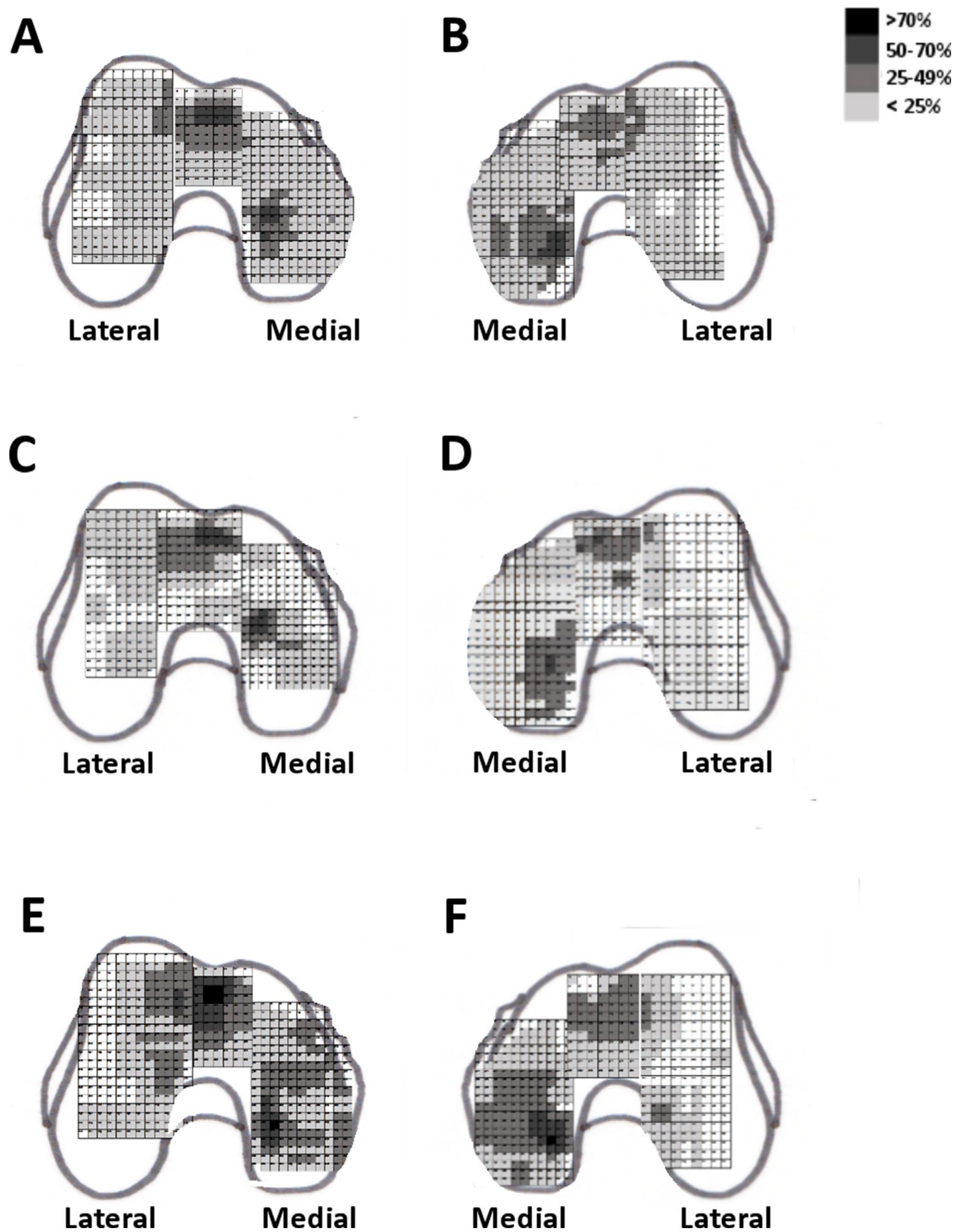

Fig. 4. Wear area and patterns of the femur. Right (A, C, E) and left femur (B, D, F). A, B: Female and male wear pattern; C, D: Female wear pattern; E, F: Male wear pattern.

lateral half of the patella unloading. These previous studies may account for the observed common areas of wear being the medial facet and medial aspect of the lateral facet of the patella.

4.2. Femur – general wear pattern

More wear was observed in the posterior aspect of the medial and anterior aspects of the medial femoral condyle. As stated above, the medial facet of the patella was a common wear area; and therefore, the anterior aspect of the medial femoral condyle is an understandably a common wear area as it articulates with the medial facet of the patella.

The posterior aspect of the medial femoral condyle is the contact area for both the patellofemoral joint and tibiofemoral joint.[13] Regarding the patellofemoral joint, the odd facet makes contact with the posterior aspect of the medial femoral condyle during deep flexion of the knee. Traditional Japanese styles of sitting such as cross-legged or with feet folded beneath the buttocks, require deep flexion of the knee. As seen in daily life, elderly Japanese people still hold to this tradition, which is why we consider this may be the reason why this common wear area.

The posterior aspect of the medial femoral condyle is also a contact area for the tibia when in slight knee flexion, at approximately 30°.[13] During weight bearing such as gait, the medial compartment absorbs a greater load (i.e., 60–80%) compared to the lateral compartment.[27] Recent studies have confirmed the significantly higher strain on the medial compartment during gait or a static lunge.[28–30]

Using only Japanese cadavers may provide another explanation. It is known that Asian populations commonly have different, known as varus alignments of their lower limbs compared with Western populations (Caucasian).[31,32] Varus alignment, resulting in a decreased Q-angle, causes larger load on the medial compartment and increases the risk of medial OA progression.[26,33] This may explain why more wear was common in the medial femoral condyle than the lateral femoral condyle.

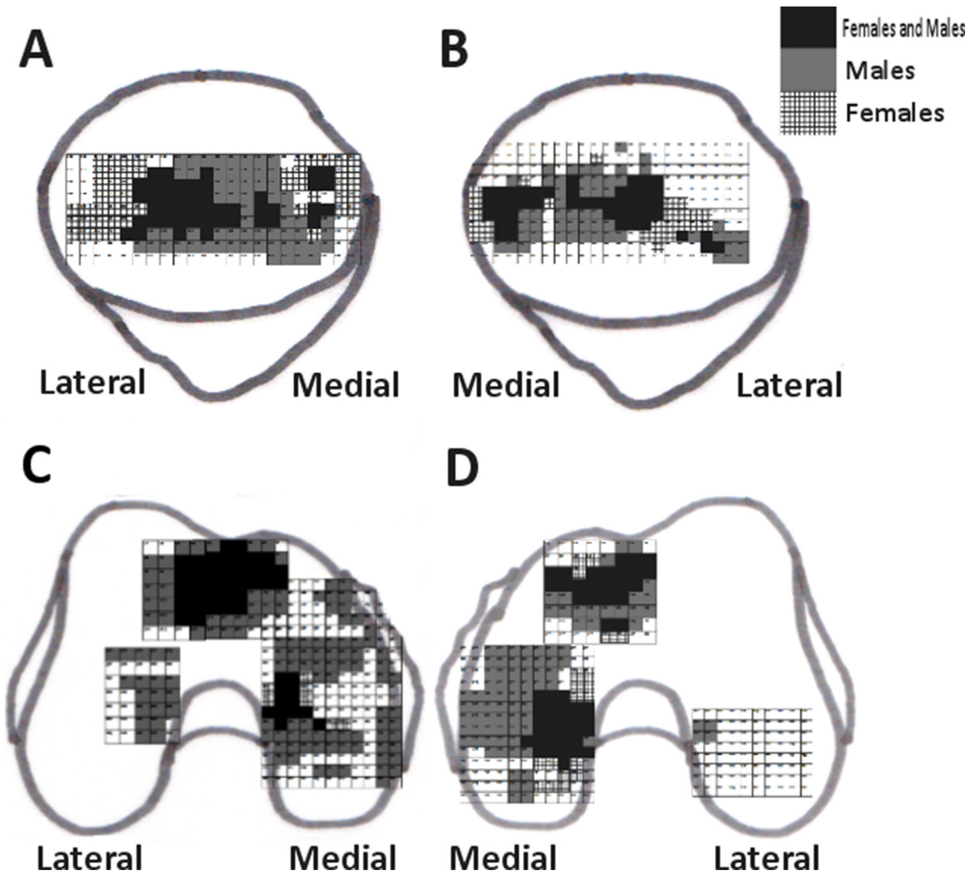

Fig. 5. Overlapping of female and male wear patterns. Wear observed in more than 50% of female and male cadavers overlapped.

Table 2
Rating of Surface Distribution per Joint Articular Area and Gender.

Area	Female N	Rating	N	Male Rating
Right Patella	19	I–II	16	I–II
	III–IV	14	13	III–IV
Left Patella	19	I–II	8	I–II
	9	III–IV	15	III–IV
Right Femur	15	I–II	12	I–II
	15	III–IV	18	III–IV
Left Femur	23	I–II	14	I–II
	12	III–IV	20	III–IV

N = number of surfaces seen on joint surface. The magnitude of wear was rated from 0 to IV: 0 = none; I = minimum (soft and swollen cartilage); II = mild (surface cracks, fissure in an area with a diameter less than 1.5 cm); III = moderate (surface cracks, fissure in an area with a diameter greater than 1.5 cm); and IV = severe (exposed subchondral bone).

Table 3
Wear area of the patella and distal femur of Male (n = 11) and Female (n = 12) Specimens.

	Males Mean ± SD	Females Mean ± SD	P
Right patella (mm^2)	385 ± 201*	202 ± 109	<0.05
Left patella (mm^2)	326 ± 160**	283 ± 260	0.64
Right femur (mm^2)	636 ± 393*	287 ± 236	<0.05
Left femur (mm^2)	693 ± 608**	365 ± 552	0.19

* $P < 0.05$ (compared with the patella and femur of female).
** $P > 0.01$ (compared with the patella and femur of female).

4.3. Females vs. Males

The pattern of patellar wear was more central and compact in males than in females (Fig. 5A, B). Females showed more wear on the lateral facet of the patella, extending to the medial aspect of the lateral facet. Generally, females have wider pelvis and more lateral trochlea angle than males, contributing to a greater knee abduction angle[34,35] and increased Q-angle.[27] Increased Q-angle also leads to increased lateral patellofemoral contact pressure.[26,38] Our observation that increased wear in the lateral facet of females may reflect this structural difference of structure in females and males.

Table 3 shows that the total wear area was larger in males than females, which is consistent with previous studies.[17,38] This can be explained by evidence from previous studies that demonstrated that males have significantly larger areas of patellofemoral joint contact than females.[38,39] Although we did not measure the joint contact area, larger bony geometry in Japanese males compared with Japanese females, was confirmed in our study and may help explain the larger wear area in males.

Another possible explanation may be due to differences in postures or activities between females and males. Several studies have shown that the size of contact area is highly dependent on knee flexion position, which remains constant up to approximately

Table 4
Comparison of wear severity between Japanese and US cadavers (Gorniak, 2009).

	Patella		Femur	
	Grade II or less	Grade III or IV	Grade II or less	Grade III or IV
US	24 %	76 %	46 %	52 %
Japanese	23 %	77 %	17 %	83 %

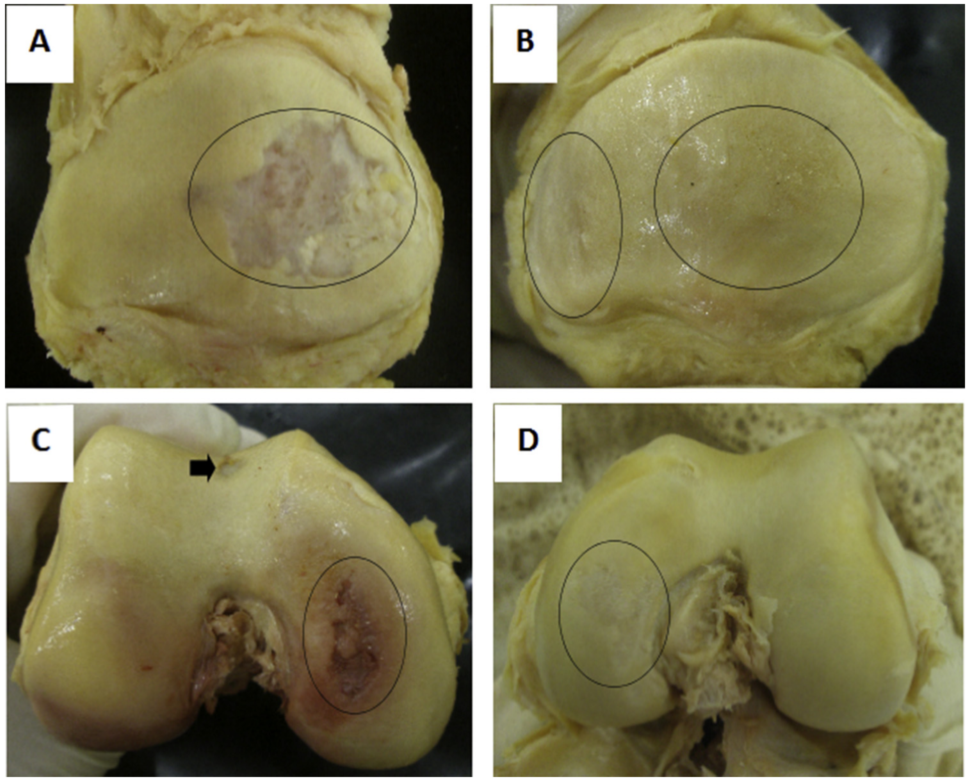

Fig. 6. Articular surfaces of patella and femur. A: Left patella of 86-year-old male was rated as IV (circled). B: Right patella of 91-year-old male rated as III (two circled). C: Right femur of 91-year-old male rated as IV in the posterior aspect of the medial femoral condyle (circled). Arrow shows wear rated as III in the anterior aspect of the medial femoral condyle. D: Left femur of 87-year-old male rated as III in the posterior aspect of the medial femoral condyle (circled).

90° of flexion.[38,39] However, to the best of our knowledge, no study has investigated if Japanese males spend more time in positions of deeper knee flexion, of up to 90° during their daily activities than females do. Additional studies are needed in the future to conclude.

An additional observation was that males have more severe wear than females (Table 2). Generally, in physiological terms, as the load bearing contact area becomes larger, the pressure on it decreases. This is a possible explanation for the more severe wear observed in males and is further supported by a previous study.[38]

Age and weight are known as risk factors for OA, as they are more frequently seen with increased age and weight. However, no significant differences in age and BMI between females and males were found in this study. Therefore, we can eliminate influence of these factors.

4.4. Japanese vs. US

The common areas of wear of the patella and femur found in the Japanese cadaver were consistent with those in US cadavers, as reported in our previous study (Figs. 3 and 5).[11] The severity of the patella wear between Japanese and US cadavers were also similar. However, Japanese cadavers tended to show more severe wear in the femur than that found in the US cadavers (Table 4). In the tibiofemoral joint, significantly higher contact force occurs at deeper flexion of the knee. However, the force of patellofemoral contact is reduced at deep flexion of the knee.[39,42] Accordingly, different life styles in the Japanese population from that of the US population, requiring deep flexion of the knee, may influence the severity of wear in the femur and the tibiofemoral joint component. This finding is supported by previous epidemiological research that has shown a higher incidence of knee OA in an Asian population than in the Western population.[42]

5. Conclusion

The patella and femur both show distinct regions of articular cartilage wear. There is greater odd, and middle part of the medial patellar facet wear than lateral facet wear. The posterior aspect of the medial femoral condyle and anterior aspect of the medial femoral condyle showed common areas of wear. These wear patterns and locations suggest that wear occurs mainly when the knees are moderately and deeply flexed and that these wear patterns may result from common traditional Japanese style of knee positions or activities. The femur possibly shows more severe wear than US cadavers (Fig. 6).

Conflict of interest

The authors declare that there is no conflict of interest.

Acknowledgments

We are grateful to the Hamamatsu University School of Medicine for use of facilities and for providing the cadavers used in this study. We would like to thank those men and women who donated their bodies for medical education.

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