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ORIGINAL ARTICLE – OPEN ACCESS

The Calculation of the Femoral Condyle Cartilage Volume and Surface Area in Patients with Osteoarthritis

Demet Ünalmış[1], Niyazi Acer[1], Seher Yılmaz[2], Adem Tokpınar[2], Serap Doğan[3], Hüseyin Demir[4]

ABSTRACT

Objective: Osteoarthritis is non-inflammatory, degenerative, and chronic disease observed, especially as progressive in load-bearing joints. There are several studies that measure the volume and surface area of the knee joint cartilage in osteoarthritis patients. However, different methods were used in these studies.

Materials and Methods: Our study population consisted of 25 patients with osteoarthritis of the knee. Twenty-five healthy individuals were included in this study as a control group. In our study, planimetry and quadratic ruler method, which are among stereological methods, were used over magnetic resonance imaging (MRI) to measure the femoral condyle cartilage volume and surface area.

Results: The average cartilage volume measurement 6.54 cm^3 in the female patient group and 13.51 cm^3 in the female control group. In this measurement, 7.49 cm^3 in male patients was measured in the control group 15.71 cm^3. In the statistical comparison between the groups, it was determined that the values in the patient group decreased significantly compared with the control group ($p<0.001$).

Conclusion: When compared with the literature, it is concluded that our method may be used as a valid method because the survey results are close to each other and the average values.

Keywords: Knee osteoarthritis, stereology, MRI, femoral condyle

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[1]Department of Anatomy, Erciyes University Faculty of Medicine, Kayseri, Turkey
[2]Department of Anatomy, Yozgat Bozok University Faculty of Medicine, Yozgat, Turkey
[3]Department of Radyology, Erciyes University Faculty of Medicine, Kayseri, Turkey
[4]Department of Physical Treatment and Rehabilitation, Erciyes University Faculty of Medicine, Kayseri, Turkey

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Correspondence
Adem Tokpınar,
Yozgat Bozok University Faculty of Medicine, Department of Anatomy, Yozgat, Turkey
Phone: +90 507 708 48 98
e-mail: ademtokpinar@gmail.com

INTRODUCTION

Osteoarthritis (OA) is one of the most prevalent conditions resulting in disability, particularly in the elderly population and shows slowly progressive degenerative disease characterized by a gradual loss of articular cartilage (1, 2). It is stated in the literature that measurements of articular cartilage volume with MRI appear to be a valid and reliable method. There are many studies in the literature evaluating the knee joint cartilage volume, and the thickness, surface area, and knee joint cartilage volume were measured (3, 4). In some of these studies (5, 6), individuals with knee OA were compared with healthy controls, and different results were obtained. Radiographically, 11–13% of the cartilage volume was lost in the first-degree narrowing of the joint space (7–9).

In addition to all these findings of OA, MRI has unquestionable value in cartilage evaluation. Morgan et al. (10) evaluated knee joint cartilage volume in different cities using three different MR devices. A 9% difference in total knee cartilage volume was observed between the devices. Ding et al. (11) investigated the relationship between knee cartilage joint volume and physical activity, age, and bone mass. MR images were used. Three hundred seventy-two individuals were included in the study. Cartilage volume among women and men varied between 33% and 42%, and this rate was higher in men than in women ($p<0.001$).

Although there are many research studies on the articular cartilage of the knee joint, to our knowledge, there are no studies in which both stereological and planimetric methods were used. The Cavalieri principle of stereological approaches allows the researchers to obtain the volume of the object of interest using sections or section images (12). It is supported that a 5–10% coefficient of error reported in the studies is sufficient for the measurement of many organs based on the Cavalieri principle. It is reported in the literature that at least 6–7 sections should be taken for an organ and that the total number of dots corresponding to all sections should not be less than 100–200. The coefficient of error is expected to fall below 5% as a result of this application (13, 14). In our study, the coefficient of error of the femoral condyle cartilage volume with the Cavalieri principle was calculated below 6%.

The present study aims to calculate the cartilage volume and surface area from MR images using different methods in the control and patient groups and to assess the measurement differences between the methods in both groups. In this context, the femoral condyle cartilage volume and surface area were calculated from MR images of the patients with knee osteoarthritis using stereological methods, and the results were compared with the control group.

MATERIALS and METHODS

This study was carried out on MR images of the patients who were admitted to Erciyes University Gevher Nesibe Hospital due to knee pain. This study was approved by the Ethics Committee of the Erciyes University, Faculty of Medicine in Turkey.

Our study included 25 patients and 25 healthy controls. The patient group was composed of patients with knee OA. The control group was composed of patients without cartilage degeneration. MR imaging was performed according to the protocol below.

MR Imaging Protocol

It was performed using a 1.5-T scanner (Magnetom Aera; Siemens, Erlangen, Germany). T2 Star Map (FFE sequence) was taken, and the following technical parameters were applied: TR (Repetition Time)=250 msn, TE (Echo Delay Time)=38 msn, FOV (Field of View)=160 mm, matrix=256x256, flip angle=60°, cross-sectional area=0 mm, image voxel=1.4x1.4x2 mm, and section thickness=3 mm.

Stereological methods were used to calculate the femoral condyle cartilage volume and surface area.

Volume Calculation

Volume calculations were made using two different methods. In the first method, the planimetric volume estimation formula based on the Cavalieri principle was used.

$$V=t\times(a_1+a_2+a_3+\cdots a_n)$$

In this formula, $(a_1+a_2+a_3+\cdots a_n)$ denote the section areas in cm^2, and (t) is the sectioning interval in cm for the n consecutive sections (15).

The second method was performed using a square grid molded ruler for calculating the volume. The corners of each square were considered as a dot, and these dots were counted in calculating the volume (Fig. 1).

$$V = t\times\left[\frac{SU\times d}{SL}\right]^2\times\sum P\ cm^3$$

In this formula, (t) is the average section thickness, (SU) is the length represented by the scale indicating the image magnification, (d) is the distance between two dots on a square grid molded ruler, (SL) is the length of the scale on the image measured by a ruler or a caliper, and ∑P is the total number of dots counted for each projection area (16).

Surface Area Calculation

A square grid molded ruler was randomly thrown on the sagittal section of the MR image, and it was performed by counting each line corresponding to the surrounding cartilage (Fig. 2) (17).

$$S = T\times d\times(I_1+I_2+I_3+\cdots+I_n)$$

Statistical Analysis

Histogram and q-q plots were examined. Shapiro-Wilk's test was applied to assess the data normality. Levene test was used to assess variance homogeneity. To compare the difference among groups, independent samples t-tests were used for continuous variables. The relationship between quantitative data was analyzed using the Pearson correlation analysis. Two methods were compared using the Passing-Bablok regression analysis. Systematic and proportional errors were considered based on the confidence intervals of the estimated regression coefficients. A systematic error was considered to be present if the confidence interval of the constant excludes 0, while a proportional error was considered to be present if the confidence interval of the slope excludes 1. Moreover, intraclass and concordance correlation coefficients were calculated with 95% confidence intervals. Analysis was conducted using Turcosa Cloud (Turcosa Ltd Co, Turkey) statistical software. A p-value of less than 5% was considered statistically significant.

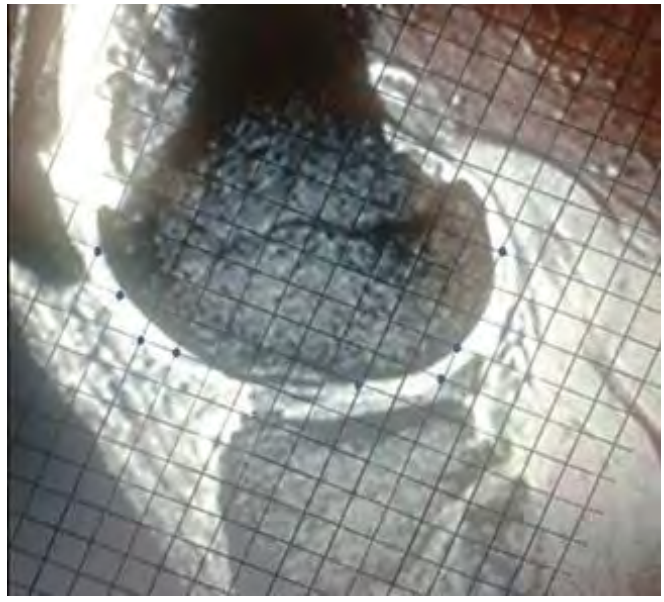

Figure 1. Counting the dots corresponding to the cartilage image (the blue dots show the dots corresponding to the cartilaginous surface)

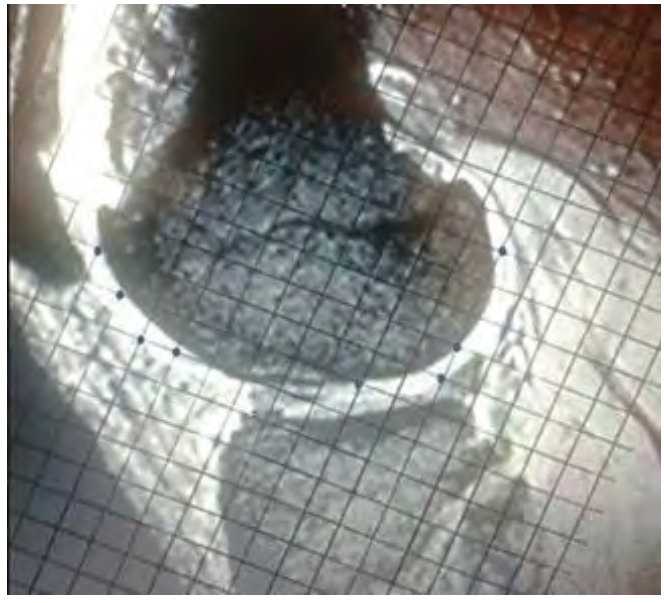

Figure 2. Counting the lines that intersect the surrounding cartilage

Table 1. The minimum, maximum, mean, and standard deviation values of the femoral condyle cartilage volume and surface area in all individuals included in this study

Methods	Groups (control group: CP, patient group PG)	Minimum	Maximum	Mean±SD
Planimetric measurement-1 (cm^3)	CG	11.14	18.12	14.75±2.12
	PG	5.17	10.52	7.00±1.38
Planimetric measurement-2 (cm^3)	CG	11.25	18.28	14.73±2.28
	PG	5.20	10.78	7.09±1.41
Square grid measurement (cm^3)	CG	10.48	18.60	14.64±2.59
	PG	5.72	11.88	7.26±1.53
Surface area measurement (cm^2)	CG	8.06	11.47	9.76±1.04
	PG	5.09	10.22	6.58±1.39

SD: Standard deviation. Values are expressed as mean±SD

Table 2. Intraclass Correlation Coefficient (ICC) values between methods

Methods	Passing-Bablok		ICC (95 CI%)		CCC (95 CI%)
	β_0 (95 CI%)	β_1 (95 CI%)	Coefficient	p	Coefficient
Planimetric volume 1- Square grid measurement	0.080 (-0.426–0.627)	1.00 (0.926–1.067)	0.98 (0.95–0.989)	<0.001***	0.979 (0.964–0.988)
Planimetric volume 2- Square grid measurement	-0.033 (-0.518–0.544)	1.006 (0.943–1.058)	0.982 (0.968–0.99)	<0.001***	0.981 (0.967–0.989)

*p<0.05; **p<0.01; ***p<0.001; CI: Confidence interval; ICC: Intraclass correlation coefficient; CCC: Concordance correlation coefficient

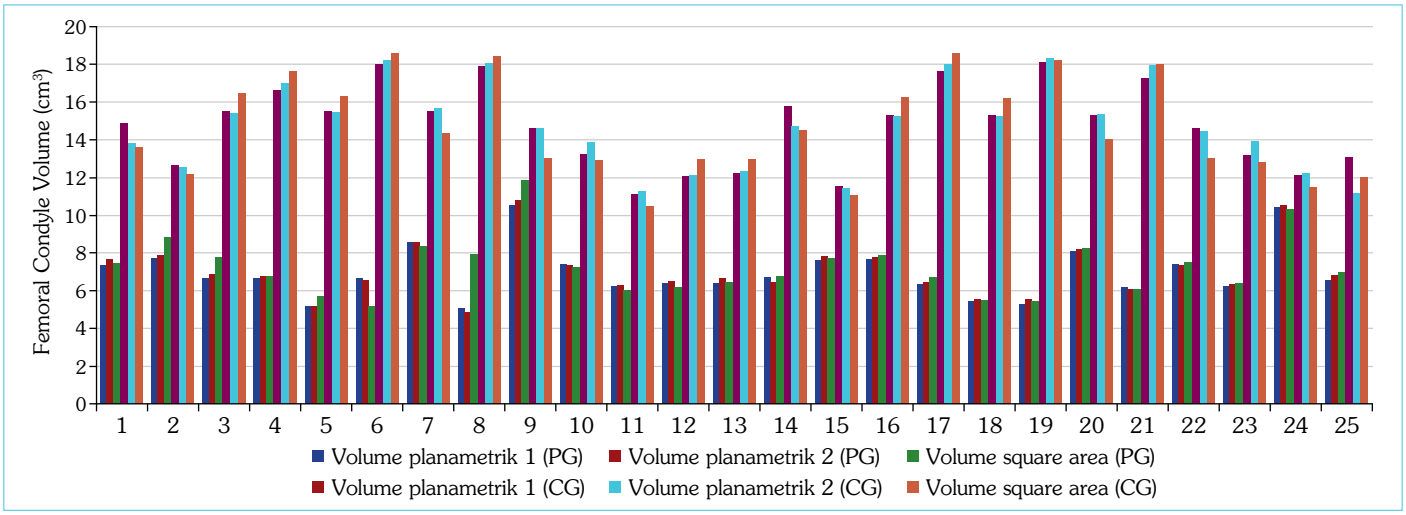

Figure 3. Comparison of volume values measured in the patient and control groups

RESULTS

Femoral Condyle Cartilage Volume Values

For all the individuals included in this study, the values of the femoral condyle cartilage volume and surface area that were measured according to the planimetric method and a square grid molded ruler are given in Table 1.

In both groups, the values that were obtained from two separate calculations according to the planimetric method and from the calculation of the distal femoral cartilage volume by the square-grid method are shown in Figure 3 as comparative values for each case. When the graph is examined, it is seen that the volume values are close to each other.

The ICC was used to determine the relationships between the two-volume values according to the planimetric method and the volume value according to the square-grid method. There was a strong correlation between them. The obtained values were greater than 0.90 (Table 2).

Table 3. Statistical comparison of cartilage volume and surface area values in both groups

Methods	Control group	Patient group	p
Planimetric 1 (cm^3)	14.75±2.12	7±1.38	<0.001***
Planimetric 2 (cm^3)	14.73±2.28	7.09±1.41	<0.001***
Square grid measurement (cm^3)	14.64±2.59	7.26±1.53	<0.001***
Surface area measurement (cm^2)	9.76±1.04	6.58±1.39	<0.001***

*p<0.05; **p<0.01; ***p<0.001; Values are expressed as mean±Standard deviation

The volume formula was used as indicated in the method, and the mean value of femoral condyle cartilage volume was 14.73±2.28 cm^3 in the control group and 7.09±1.41cm^3 in the patient group. When the patient and control groups were compared, it was determined that the values of the femoral condyle cartilage volume were greater at a statistically significant level in the control group than in the patient group (p<0.001) (Table 3).

Femoral Condyle Cartilage Surface Area Values

When the values of the femoral condyle cartilage surface area were evaluated, it was observed that there was a significant difference between the patient and control groups (Fig. 4).

The Pearson Correlation Analysis was used to determine the relationship between the methods concerning the femoral condyle cartilage volume and surface area. There was a strong correlation between the methods (Table 4). The surface area formula was used as indicated in the method, and the mean value of the femoral condyle cartilage surface area was 9.76±1.04 cm^2 in the control group and 6.58±1.39 cm^2 in the patient group. When the patient and control groups were compared, it was determined that the mean value of the femoral condyle cartilage surface was greater at a statistically significant level in the control group than in the patient group (p<0.001) (Table 3).

Variability of the Femoral Condyle Cartilage Volume and Surface Area according to Gender

In our study, there were 11 women and 14 men in the control group and 13 women and 12 men in the patient group. Independent samples t-tests were used to determine whether the femoral condyle cartilage volume and surface area varied according to gender. Accordingly, the values of the femoral condyle cartilage volume and surface area in the patient and control groups are shown according to gender in the following table (Table 5, 6).

The value of the femoral condyle cartilage volume was greater at a statistically significant level in men than in women (p<0.05). In the patient group, the presence of knee osteoarthritis did not differ according to gender (p>0.05).

In our study, the coefficient of error for the femoral condyle cartilage volume with the Cavalieri principle varied between 3% and 5% (mean=4.3%) in the control group and between 5% and 8% (mean=5.4%) in the patient group.

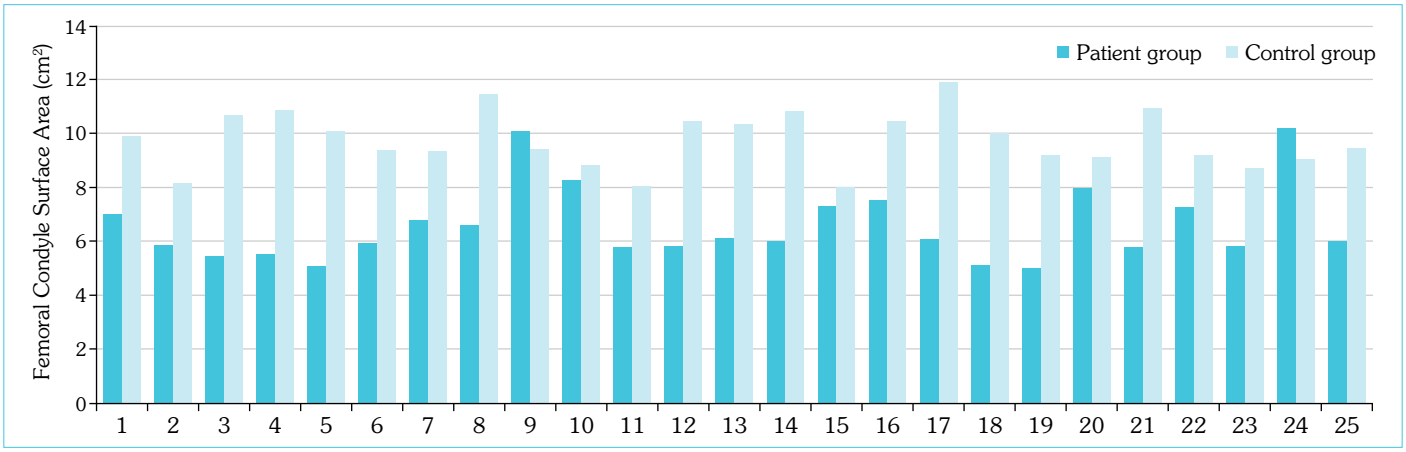

Figure 4. Comparison of surface area values measured in the patient and control groups

Table 4. Correlation values for the femoral condyle cartilage volume and surface area in all individuals included in this study

Methods	Square grid measurement r	Planimetric measurement-1 r	Planimetric measurement-2 r	Surface area measurement r
Square grid measurement	1	0.980	0.981	0.904
Planimetric measurement 1		1	0.995	0.898
Planimetric measurement 2			1	0.890
Surface area measurement				1

r: Correlation value

Table 5. Values of the femoral condyle cartilage volume in the patient and control groups according to gender

Volume (cm^3)	Planimetric 1 (cm^3)			Planimetric 2 (cm^3)			Square grid measurement (cm^3)		
	Female	Male	p	Female	Male	p	Female	Male	p
Control group	13.51±1.76	15.71±1.92	0.007**	13.56±2.02	15.64±0.56	0.020*	13.06±0.57	15.87±0.65	0.004**
Patient group	6.54±0.97	7.49±1.60	0.082	6.61±0.98	7.60±1.66	0.082	6.64±1.16	7.93±1.64	0.032*

*p<0.05; **p<0.01; ***p<0.001; Values are expressed as mean±Standard deviation

Table 6. Values of the femoral condyle cartilage surface area in the patient and control groups according to gender

Surface area (cm^2)	Female	Male	p
Control group	9.42±0.85	10.02±1.13	0.162
Patient group	5.78±0.66	7.44±1.49	0.003*

*p<0.05; **p<0.01; ***p<0.001. Values are expressed as mean±Standard deviation

DISCUSSION

MRI is important in the early diagnosis of any pathological condition (18). In evaluating soft-tissue changes, MR imaging is widely used clinically because it has a high resolution and takes images from different sections. Intra-articular pathologic conditions can be observed when the tissue is examined in the most accurate sequence. Thus, MRI is the most appropriate imaging method in cases causing damage to the joint structure and in diseases characterized by articular cartilage degeneration and in clinical conditions showing signs of joint pain, stiffness, and limitation of movement (19–23).

Faber et al. (3) (2001) examined the differences in knee joint cartilage thickness, volume, and surface area according to gender in a study group of young, healthy sedentary individuals. A three-dimensional MRI protocol was used. They reported that the mean femoral cartilage volume was 11.8 cm^3 in women and 15.0 cm^3 in men. They also found that the mean femoral cartilage surface area was 5.4 cm^2 in women and 6.5 cm^3 in men. Hudelmaier et al. (6) (2003) investigated the correlation between anthropometric features of individuals, muscle cross-sectional areas, and morphological characteristics of knee joint cartilage. Fifty-nine asymptomatic individuals aged between 23 and 75 years participated in this study. MR images were used in cartilage evaluation. The mean knee joint cartilage volume was 9.9 cm^3 in women and 13.9 cm^3 in men. In the control group in our study, the femoral condyle cartilage volume was 13.5 cm^3 in women and 15.7 cm^3. The femoral condyle cartilage surface area was 9.4 cm^2 in women and 10 cm^2 in men.

In a study conducted by Eckstein et al. (4) (2001), they examined knee joint cartilage volume, surface area, and thickness using three-dimensional MRI protocol and assessed inter-individual variability and correlation. The mean value of the femoral cartilage volume was calculated as 13.4 cm^3 and the mean value of the femoral cartilage surface area was calculated as 7.8 cm^2. The maximum cartilage thickness was observed on the patella. There was a correlation between the cartilage thickness and the volume and between the surface area and the volume (r=0.80, r=0.56, respectively). In our study, the femoral condyle surface area was measured by one method, and the femoral condyle volume was measured by two different methods. There was a strong correlation between the volume and the surface area in both methods.

In a study by Eckstein et al. (24) (2002), they examined the variations in knee joint cartilage surface area and thickness. High-resolution and high-contrast three-dimensional MRI protocols and sagittal sections were used for calculation. Fourteen volunteers participated in the study. Long-term and short-term MRI scan protocols were compared in the study, and the total knee joint cartilage volume (femoral and tibial condyles) varied from 18 to 28 cm^3.

Raynould et al. (5) (2003) investigated the differences in cartilage thickness and volume using MR images in healthy controls and individuals with OA. In this study, 48 MR images were used. The ICC values of the results were between 0.95 and 0.99 for all cartilage. According to the Pearson Correlation Analysis, the p-value was below 0.001. In our study, the ICC values between inter-method volume values varied between 0.95 and 0.99 in all participant.

In a study by Nishimura et al. (25) (2005), they investigated whether the physical characteristics of the individuals varied in knee joint cartilage volume. Sixty-eight individuals participated in their study. Three-dimensional MR images were used. The mean knee joint cartilage volume was 8.3 cm^3 in men and 6.7 cm^3 in women.

Buendia-Lopez et al. (26) also assessed the articular thickness in all knee articular compartments and reached a similar conclusion.

Kato et al. (27) (2017) investigated the knee cartilage volume in patients who had undergone ACL reconstruction surgery. They found that the knee cartilage volume in the ImageJ was 2038 mm^3.

Pan et al. (28) (2017) investigated the relationship between knee pain and knee cartilage volume loss in elderly people without osteoarthritis. They found that the tibiofemoral compartment is 13.4 cm^3, and there was a relationship between pain and cartilage volume loss.

In our study, the femoral condyle cartilage volume and surface area were calculated on MR images using the stereological methods. The cartilage volume was calculated by two different methods. Cartilage surface area was calculated by one method. Given that our results are close to the average when compared to other studies, this shows that our method is accurate. In addition, because the difference between the methods in calculating cartilage volume was not statistically significant, the methods we used can be used in calculating cartilage volume.

There were some limitations to our study. First, our subject population consisted of only 25 patients and 25 controls. Our findings

need to be confirmed on a larger population for better statistical comparison. Second, our participants were not equal for ages and count both genders. Thus, we cannot generalize our results for both genders. Future studies should encompass both genders.

Our study shows that the femoral condyle cartilage volume and surface area are significantly reduced in the presence of knee osteoarthritis. Moreover, the femoral condyle cartilage volume and surface area varied according to gender, and the surface area was wider and the volume was larger in men than in women. Given that the methods we used gave statistically similar results and had a similarity with the results found in the literature demonstrates that our method is accurate and reliable. The femoral condyle cartilage volume was measured twice with the planimetric method and once with the square-grid method, and also the surface area was measured. Consequently, the original aspect of this study was that the square grid design, which was used in calculating the surface area, was adapted to a square grid molded ruler used in calculating volume by counting the corners of the squares as a dot.

Ethics Committee Approval: This study was approved by the Erciyes University Clinical Research Ethics Committee (date: 21.03.2014, number: 2014/183).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – DÜ; Design – NA; Supervision – DÜ; Resource – SY; Materials – HD; Data Collection and/or Processing – SD; Analysis and/or Interpretation – DÜ; Literature Search – DÜ; Writing – DÜ; Critical Reviews – AT.

Conflict of Interest: The authors have no conflict of interest to declare.

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