ORIGINAL STUDY — HIP

acta orthopaedica belgica, 2025, 91, 179-185

doi.org/10.52628/91.1.14122

# Examination of proximal femur bone in unilateral end-stage hip osteoarthritis using fractal analysis

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**Osteoarthritis (OA) is the most common joint disorder and the microstructural changes in trabecular bone remain unclear. The present study aimed to evaluate the fractal dimensions of the trabecular bone structure of the femoral neck on pelvic radiograph images of patients with unilateral end-stage hip OA. The trabecular structures of the femoral neck of 130 patients (57 with right-sided hip joint OA and 73 with left-sided hip joint OA) were evaluated and compared with the Fractal Analysis Method, taking into account gender and hip joint orientation. The fractal dimension calculated from the femoral neck on the right and left sides was similar to the healthy side in individuals with OA (p=0.647, p=0.929, respectively). When OA and healthy joints were compared separately on the right and left sides, the value on the osteoarthritic side was found to be significantly lower (p<0.05). When examined without distinguishing between the right and left sides, the fractal dimensions were found to be significantly lower in osteoarthritic joints than in the healthy side (p=0.001). When gender was taken into account, the fractal dimension calculated in both healthy individuals and individuals with OA was found to be similar in women and men (p>0.05). The fractal dimensions of the femoral neck trabecular structure of the osteoarthritic hip joint that was evaluated in pelvis radiography were low on the osteoarthritic side. With its cost-free and harmless use, the Fractal Analysis Method can be used by clinicians in planning therapeutic procedures in OA in the medical examination of OA patients.**

**Keywords: Fractal analysis, pelvis radiography, end-stage hip osteoarthritis, femoral neck, trabecular bone structure**.

## INTRODUCTION

In adults, Osteoarthritis (OA) is the most common disease of the hip joint and early detection of hip joint arthrosis is important because of its high socioeconomic impact. Conventional X-rays remain indispensable as the first-line technique for diagnosing hip joint OA[1]. OA is characterized by progressive structural changes in the cartilage and the underlying subchondral bone, but the spatial relationships between the severity of the cartilage lesion and the microstructural changes in the subchondral plate and trabecular bone remain unclear[2].

The effects of OA on trabecular bone structure were emphasized in a previous study that provided a comprehensive evaluation of the heterogeneous microarchitectural characteristics of the femoral head[3]. As aging is an important risk factor for OA, it is important to know the microstructural changes occurring in the subchondral bone of the femoral head[4].

Although Projection Radiography, which is the standard diagnostic method in OA, enables the detection of subtle changes in cortical contours and joint space width with its high spatial resolution, its sensitivity for detecting changes in trabecular bone structure is low[1,5].

Fractal Analysis (FA) is a mathematical method used to determine the complex shapes and patterns of the structure, and the numerical result is given as Fractal Dimension (FD). Many studies evaluated the effects of diseases such as diabetes, osteoporosis, hypoparathyroidism, and drugs such as bisphosphonate, aromatase, etc. with FA[6-10].

The purpose of the present study was to compare the trabecular bone structure of the femoral neck of the side where arthroplasty was performed because of OA

and the contralateral, i.e. healthy, side by using the FA Method on preoperative radiography images of end-stage unilateral hip OA patients.

## MATERIALS AND METHODS

Ethical approval was obtained from the Bolu Abant Izzet Baysal University Non-Intervantional Clinical Research Ethics Committee for the study (2024/88). Pre- and postoperative pelvic radiograph images of patients who applied to the Department of Orthopedics and Traumatology between 2020 and 2023 and underwent unilateral total hip arthroplasty surgery because of end-stage OA were examined in the study. The side with the hip prosthesis and the healthy side were recorded on the postoperative radiograph images of the patients. Then, the trabecular characteristics of the femoral neck on the side with end-stage unilateral hip OA and the contralateral side without OA, which was called the healthy side, were evaluated by using the FA Method on preoperative radiograph images.

*Inclusion criteria*

- Having undergone unilateral total hip arthroplasty surgery because of OA
- Not having any pathology that might affect proximal femur morphometry on pelvis Anterior-Posterior (AP) radiograph
- Not having inflammatory arthritis, trauma, joint surgery, congenital skeletal system diseases
- Being a volunteer

*Exclusion criteria*

- Not having had unilateral total hip arthroplasty surgery
- Having any pathology that might affect proximal femur morphometry on pelvis Anterior-Posterior (AP) radiograph
- Having inflammatory arthritis, trauma, joint surgery, congenital skeletal system diseases
- Not volunteering

*Evaluation of the images*

Fractal analysis (FA) was performed on the patients' X-ray images with dimensions of 1667x957 pixels using the Image J program (National Institutes of Health MD, USA) with White and Rudolph's box-counting method. The ROI of 40x40 pixel size was selected on the femoral neck both the healthy and diseased sides (Figure 1). After the ROI was duplicated in JPEG format, the soft tissue covering the bone and bright areas resulting from the variable thickness of the bone were blurred by the Gaussian blur filter on the ROI. The blurred image subtracts the original image and 128 gray values added the each pixel of ROI. Trabecular and bone marrow were made visible on the image with this stage. By the threshold option (128 value) areas equal to or smaller than 128 pixels were converted to black and the others to white. The noise was reduced by the eroding and dilating options. The outlines of the trabecular were revealed by turning white areas into black and black areas


*Fig. 1 — Selection of ROI on both of right and left sides of the femoral neck.*

into white with the invert option. This trabecular structure was determined skeletally with lines by the skeletonize option and FD was calculated with the analyze option (Figure 2). These procedures were performed by the same observer.

*Statistical Analysis*

Descriptive statistics of the measurements were calculated as mean, standard deviation (SD), number, and % frequencies. The normality assumption was checked by using the Shapiro-Wilks test and it was determined that they have the normal distribution. The relationships between the numerical variables were investigated with Pearson correlation analysis. Independent samples t-test was used in the comparison of the right OA and left OA groups and genders. The osteoarthritic hip joint and the healthy hip joint were evaluated with paired samples t-test. The statistical significance level was accepted as P<=0.05. SPSS (ver. 23) program was used in the calculations.

## RESULTS

A total of 130 individuals were included in the study among whom 57 had right-sided hip joint OA and their left side was healthy. Also, the remaining 73 individuals had right-sided healthy hip joints and their left side had OA. The mean age of the 130 individuals was 58.6±11.05 (31-89) years. Also, the mean age of 57 individuals with right-sided OA and left-sided healthy was 58.8±12.86 (31-89) years and the mean age of 73 individuals with left-sided OA and right-sided healthy was 58.4±9.48 (34-79) years. A total of 39 of 130 individuals (30%) were male, 18 of 57 individuals (31.6%) with right-sided OA were male, and 21 of 73 individuals (28.8%) with left-sided OA were male.

No significant relationships were detected between age and FD in patients with right-sided OA (n=57) and left-sided OA (n=73) (p values 0.755 and 0.579, respectively). There were no significant relationships between age and FD in 57 healthy individuals with left sides and 73 healthy individuals with right sides (p values 0.260 and 0.364, respectively). In the study population, FD was not affected by increasing age on the right and left sides in both the patient and healthy groups.

FD values, which were calculated from the femoral neck on the right and left sides of OA and healthy individuals, were compared and the results are given in Table I. When the table is examined, no significant differences were detected in terms of FD on the right and left sides in both OA individuals and healthy individuals (p=0.647, p=0.929, respectively).

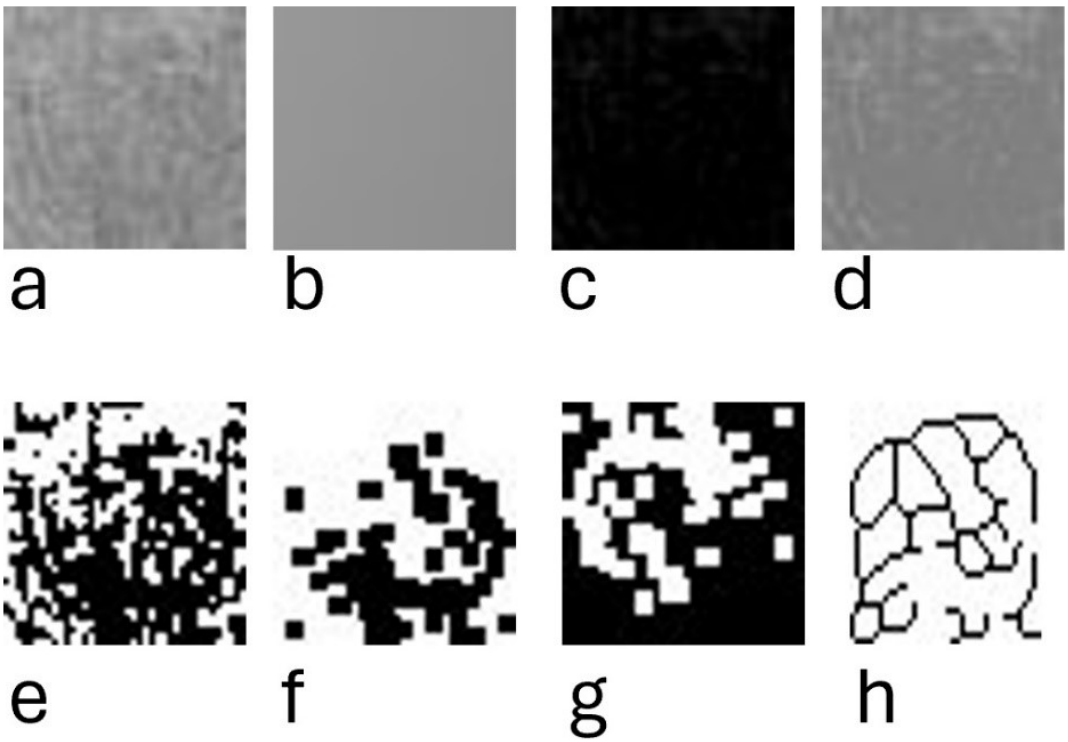


*Fig. 2 — Step of the fractal analysis a. ROI b. Gaussian blur filter c. Subtract the blurred image from the original image d. Add 128 grey value e. The threshold for converting to ROI black and white areas f. Reduce noise erode and dilate option g. Inverted h. Skeletonize.*

**Table I.** — The comparison of the right and left sides with regard to fractal dimension in osteoarthritic and healthy joints.

| Hip joint | Side | N | Mean | SD | P* |
|---|---|---|---|---|---|
| Osteoarthritis | Right | 57 | 1.28018 | 0.127846 | 0.647 |
| | Left | 73 | 1.26985 | 0.126905 | |
| Healthy | Left | 57 | 1.31079 | 0.107360 | 0.929 |
| | Right | 73 | 1.30888 | 0.129672 | |

**: Independent samples t-test.*

To investigate the effects of OA on the joint, when healthy and OA joints were compared separately on the right and left sides, it was found that FD on the OA side was significantly less than the healthy side in both cases ($p<0.05$, Table II).

When the FD values, which were calculated from OA joints, and the FD values, which were calculated from healthy joints, were compared regardless of the right and left sides, it was found that the FD in the OA joints was significantly less than the healthy side ($p=0.001$, Table III). When the FD values, which were calculated from the hip joint of OA and healthy individuals, were compared between genders, the FD values, which were calculated in both healthy individuals and OA individuals, were found to be similar in men and women ($p>0.05$, Table IV).

## DISCUSSION

It was reported in previous studies that OA affects the morphological characteristics of the femoral head and increases the heterogeneity in bone microarchitecture, which may be regionally specific[3].

In the literature, in previous studies that evaluated and compared patients with vertebral crush fractures because of osteoporosis in the postmenopausal period with patients without fractures because of osteoporosis in the postmenopausal period with femoral neck FA, authors reported that FA might be used to separate the patient and control groups[11]. To investigate the effects of FA on the trabecular structure (i.e. micro-architecture) of many diseases such as diabetes, osteoporosis, hyperparathyroidism, thalassemia, renal osteodystrophy and drugs such as bisphosphonates and aromatase inhibitors, the bone structures of patients were compared with FD calculated from the bones of healthy individuals[6-7,12,13]. As a result of these studies, it was reported that diseases and drug use caused changes in the micro-architecture of bones, which affected FD. While high FD indicates a more complex architecture, low FD indicates a decrease in trabeculation[14]. However, the visibility of trabeculae because of demineralization might cause increased FD results in some cases[15].

Dual X-Ray Absorptiometry (DXA) is considered the gold standard in measuring Bone Mineral Density (BMD) and diagnosing osteoporosis. The Trabecular Bone Score (TBS), which is the textural analysis of DXA images, is an index of bone microarchitecture in the evaluation of bone health[16]. However, one of the disadvantages of this method is the relatively high radiation exposure.

The FA Method was used in the present study on existing radiograph images to evaluate the structure of the trabecular bone. In this way, a less costly method was used by avoiding irradiation to the patient.

The trabecular structure of the bone might differ between genders and depending on age[17]. In the present study, the relationships between age and FD were analyzed in OA individuals and healthy individuals and it was found that FD was not affected by age. Similarly, FDs obtained from the femoral neck of female and male individuals in both groups were compared and no significant differences were detected between genders. In this way, the effect of age and gender on the study results was eliminated.

Previous studies that evaluated the heterogeneity and BMD in subchondral bone in regions exposed to different loads in the femoral head of individuals with OA reported differences between the deep and upper regions of the bone[18]. It was reported that the selected ROI size and the inclusion of other structures such as cortical bone in the ROI when calculating the FA would affect FD[19]. Standardization was achieved by selecting the ROI in the femoral neck, trabecular bone structure, and the same size in all patients by the same observer in the present study.

It was reported previously that OA might cause changes in bone with different severities in different stages of the disease[20,21]. In the present study, when the right and left OA sides of individuals with OA were compared, it was found that there was no difference

**Table II.** — The effect of osteoarthritis in groups with right and left-side osteoarthritis.

| Group | | Mean | SD | P* |
|---|---|---|---|---|
| n=57 | Right Osteoarthritis | 1.28018 | 0.127846 | **0.034** |
| | Left Healthy | 1.31079 | 0.107360 | |
| n=73 | Right Healthy | 1.30888 | 0.129672 | **0.006** |
| | Left Osteoarthritis | 1.26985 | 0.126905 | |
| *: *Paired samples t-test.* | | | | |

**Table III.** — Effect of osteoarthritis regardless of sides.

| | | Mean | SD | P |
|---|---|---|---|---|
| n=130 | Osteoarthritis | 1.27438 | 0.126927 | **0.001** |
| | Healthy | 1.30972 | 0.119956 | |
| *: *Paired samples t-test.* | | | | |

**Table IV.** — Comparison of osteoarthritis and healthy side in terms of gender.

| | Sex | N | Mean | SD | P* |
|---|---|---|---|---|---|
| Osteoarthritis | Male | 39 | 1.28495 | 0.125290 | 0.536 |
| | Female | 91 | 1.26985 | 0.128042 | |
| Healthy | Male | 39 | 1.31359 | 0.135523 | 0.811 |
| | Female | 91 | 1.30805 | 0.113406 | |
| *: *Independent samples t-test.* | | | | | |

in FD on the right and left sides. We think that this similarity occurred because the patients with OA were in the same stage.

A previous study investigating the causal relationship between OA and low BMD reported that osteoporosis might be causally associated with an increased risk of OA and that measures to increase BMD might be effective in preventing OA. It was also reported that the etiology and pathological changes in OA remain largely unclear, which has led to a significant lack of treatable applications[22]. For this reason, early diagnosis of osteoarthritic changes in the clinic is very important.

It was reported in a study that aimed to investigate the weight-bearing asymmetry in patients with bilateral knee OA and to clarify the relationships between the asymmetry of gait parameters and BMD that higher BMD values and loading status on the high-force side compared to the low-force side would reflect the BMD at the femoral neck in patients with bilateral knee OA[23].

Because of the retrospective nature of the present study, data on the dominant side and weight-bearing asymmetry of patients was not known. However, when the side with OA was compared to the healthy side (whether by making a distinction between right and left or without making a distinction between right and left), it was found that FD was less in OA individuals than in the healthy side in both cases. We believe that this occurred because of the decreased trabecular structure of the femoral neck caused by OA, regardless of the dominant lower extremity and weight-bearing asymmetry.

When the literature was reviewed, it was found that elderly postmenopausal women with radiographic hip and knee OA had significantly lower hip and spine BMD compared to the control group without OA. In a study, the effect of OA on bone tissue was found to be parallel to the present study[24].

It was reported that bone indices including TBS and BMD were associated with a wide range of variables including physical activity, vitamin D, liver enzymes, biochemical measurements, quality of life, mental and sleep disorders[25]. When the studies conducted on trabecular bone structure were examined, it was found that these studies aimed to determine the most important factors associated with bone indices. However, in women, the relationship between menopause status, natural or surgical menopause history, age at menopause, and the number of years of menopause is important[26].

Several limitations must be explained in the present study. Firstly, the study had a retrospective design. For

this reason, it was not possible to access the archive data on BMD and dominant side lower extremity data of OA patients. Secondly, although the fact that the right and left femoral necks of the same individuals were examined and the advanced age of both genders affected the results of the study positively, the factors affecting bone metabolism, especially menopausal status and body composition in women, were not examined in detail. Finally, the most important limitation was that the patients' BMD information and FD average could not be compared. Despite several limitations, the results of the present study provide useful data for evaluating the relationship between OA and trabecular bone structure in the femoral neck in patients with unilateral end-stage hip OA. Further studies will be needed to eliminate the limitations.

## CONCLUSION

In the present study, in which the researchers aimed to examine the femoral neck with FA to evaluate the effects of end-stage OA in the hip joint on the trabecular bone structure, it was found that the FD average decreased on the osteoarthritic side and the trabecular bone structure was affected. We believe that FA, which provides data on the trabecular bone structure of pathological changes in OA, will make a significant contribution to the use of treatable applications by the clinician with its easy and cost-free use. To understand the process of the effect of OA on the trabecular bone structure, more research is needed to determine the processes according to the disease stages.

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