International Orthopaedics (2023) 47:1323–1330
https://doi.org/10.1007/s00264-023-05742-9

ORIGINAL PAPER

Fracture mapping of adult femoral neck fractures with three dimensional computed tomography

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Received: 23 October 2022 / Accepted: 20 February 2023 / Published online: 1 March 2023

Abstract

Purpose Femoral neck fractures (FNFs) are a commonly encountered injury in orthopaedic practice. It is essential that surgeons recognize specific fracture patterns to effectively manage these fractures. The purpose of this study was to analyze the fracture morphology of FNFs by three-dimensional (3D) mapping of the fracture.

Methods The fracture line location and distribution of 120 FNFs were identified using computed tomography reconstructions. After segmentation and virtual reduction, the fracture line was revealed. The femoral neck region was divided into zones according to anatomical localization, and the zones through which the fracture lines passed were recorded. All fracture lines are superimposed on the standard model to create fracture mapping.

Results A total of 120 patients with FNFs were analyzed. The mean age of the patients was 67 (18–96) years. Of all patients, 59 were male, and 61 were female. The most affected region was Zone 4. The least affected region was Zone 6. The displacement in Zone 1 and Zone 4 was found to be significantly higher. The displacement in patients under 65 years was found to be significantly higher. Zone 2 and Zone 5 involvement was significantly higher in patients under 65 years.

Conclusion The fracture map showed fracture patterns of FNFs. It was found that fracture displacement and transcervical region involvement were more common in patients under 65 years. It was also found that the displacement rate was high in fractures of the subcapital region.

Keywords Femoral neck fracture · Computed tomography · 3D · Mapping

Introductıon

Femoral neck fractures (FNFs) are among the most common fractures and are difficult to treat in orthopaedic surgery practice. While it occurs with high-energy trauma in young patients, it can also occur with lower-energy trauma in older patients [1]. The type of treatment is planned by considering many factors, such as the patient's age, the type of fracture, and concomitant diseases. It is estimated that hip fractures will increase with increasing life expectancy, making these fractures more important [2, 3].

Better treatment planning is required for these fractures. Therefore, a better understanding of the morphological characteristics of the fracture plays a key role in making treatment decisions and the outcome of the treatment. With a better understanding of the fracture, the treatment can be planned in more detail, and thus more successful results can be obtained.

Previously, the diagnosis and classification of FNFs were made only by radiographs. Today, the use of computed tomography (CT) has become widespread for these fractures. Fracture mapping with CT is frequently used to better understand fractures. The purpose of this study was to analyze the fracture morphology of FNFs by three-dimensional (3D) mapping of the fracture lines.

Materials and methods

Our study was carried out with 120 patients who met the inclusion criteria among the patients who applied to the Gaziantep University Faculty of Medicine Orthopedics and Traumatology Department with femoral neck fractures between 2017 and 2022. Our study was designed as a single-centre study, and the datasets of patients who met the criteria

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were analyzed retrospectively. The inclusion criteria for the study were as follows: the patient had a femoral neck fracture, was 18 years of age or older, had a CT image with a section of 2.5 mm or less thickness, did not have an additional femoral fracture, had no history of previous hip or femoral surgery, and had no pathological fractures. All of the included patients' case files and imaging files were collected.

3D model reconstruction

Digital Imaging and Communications in Medicine (DICOM) images obtained from the patient's CT were loaded into the Materialize Mimics and 3-matic (Materialize, Leuven, Belgium) software. A 3D reconstruction was obtained, and the fragments were segmented. Fragments were determined, and virtual reduction was applied to these fragments by simulated repositioning (Fig. 1). While performing the reduction, anterior, posterior, superior, and inferior cortex continuity was taken as a basis in the femoral neck region. After segmentation and reduction, the fracture line was revealed.

Identification of anatomical zones in the femoral neck

The femoral neck region was divided into regions according to anatomical localization. These regions are anteriorly subcapital (Zone 1), transcervical (Zone 2), basocervical (Zone 3), posteriorly subcapital (Zone 4), transcervical (Zone 5), and basocervical (Zone 6) (Fig. 2). The fracture lines drawn for all patients were examined, and the regions where these lines passed were recorded.

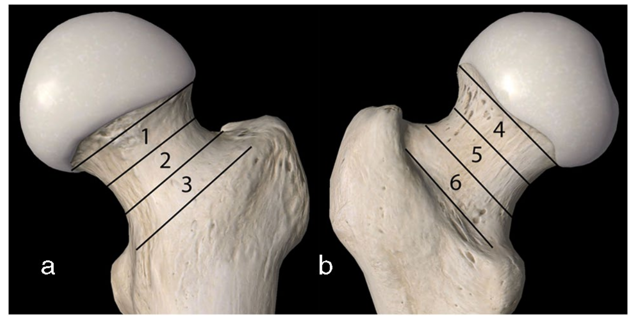


Fig. 2 Anatomical zones of the femoral neck; **a** anterior, **b** posterior view

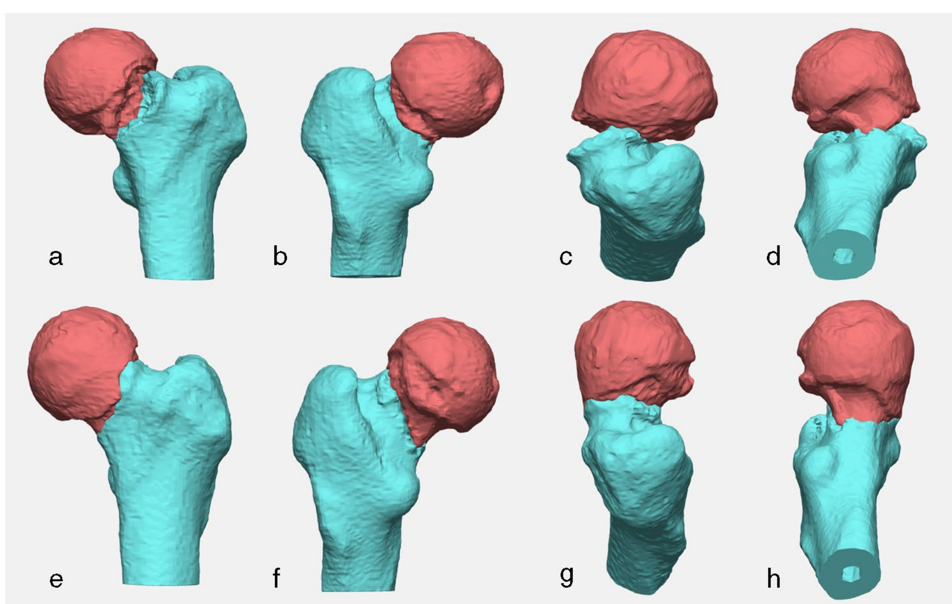
Mapping the fracture lines

Fracture mapping was performed according to the method described by Armitage and Cole et al. [4, 5]. Anterior, posterior, superior, and inferior images of a 3D proximal femur were exported from Essential Skeleton 4 (3D4 Medical, San Diego, CA, USA). After the 3D modeling was completed, the fracture lines were drawn on a standard proximal femur template with the Adobe Illustrator (Adobe Systems Incorporated, Mountain View, CA, USA) graphic design program. Fracture maps were created by overlapping the drawings of all patients in layers (Fig. 3).

Statistical analysis

Descriptive statistics of the data obtained from the study are presented as the mean and the standard deviation for numerical variables and frequency and percentage analysis

Fig. 1 3D reconstruction; **a** anterior, **b** posterior, **c** superior, **d** inferior view. Virtual reduction of fracture; **d** anterior, **e** posterior, **f** superior, **g** inferior view



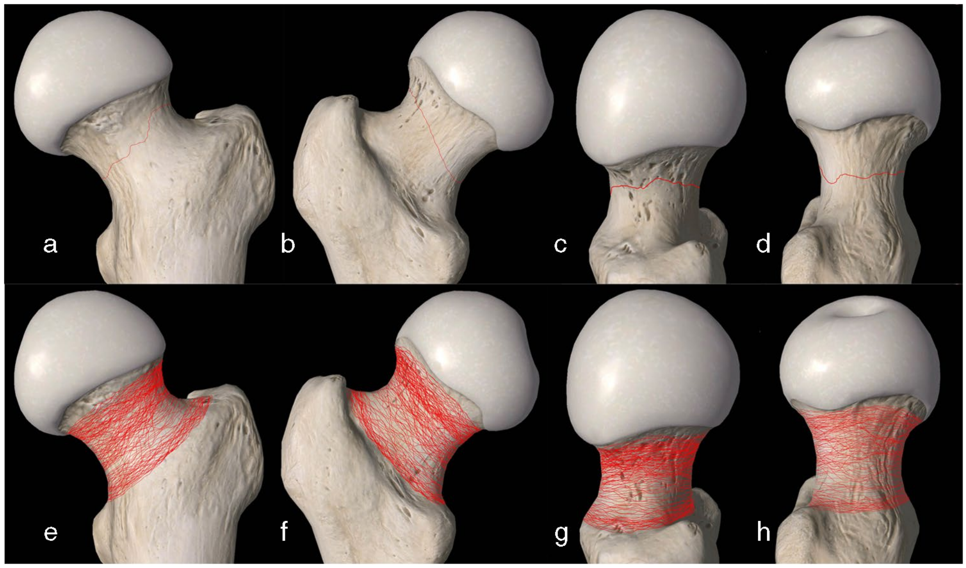


Fig. 3 Fracture lines were drawn on the temple; **a** anterior, **b** posterior, **c** superior, **d** inferior view. Overlap of all patient fracture lines; **d** anterior, **e** posterior, **f** superior, **g** inferior view

for categorical variables. Chi-square analysis was used to compare the obtained variables according to demographic data. The age distribution of patients between groups was analyzed using an independent samples t test. Analyses were carried out with the help of the SPSS 22.0 program with $p < 0.05$ significance level.

Results

A total of 120 patients with femoral neck fractures were analyzed. The mean age of the patients was 67.92 ± 17.44 (18–96). Of all patients, 59 were male, and 61 were female. While the mean age of male patients was 63.93, the mean age of female patients was 71.77. The most common mechanism of fracture was falling from their level. The demographic data of the patients are given in Table 1.

When the affected regions were examined according to age groups, Zone 2 and Zone 5 involvement was significantly higher in patients under 65 years ($p = 0.001$, $p = 0.002$). The distribution of affected zones by age is given in Table 2. In patients under 65 years, fracture displacement was observed in 38 (82.6%) patients, while eight (17.4%) were nondisplaced. In patients 65 years of age and older, fracture displacement was observed in 48 (64.9%) patients, while 26 (35.1%) patients were nondisplaced. The displacement in patients under 65 years was found to be significantly higher ($p = 0.036$). The distribution of fracture lines by age is shown in Fig. 4.

The distribution of affected zones by gender is given in Table 2. Zone 2 and Zone 5 involvement was significantly higher in male patients than in females ($p = 0.011$, $p = 0.001$). In female patients, fracture displacement was observed in 38 (62.3%) patients, while 23 (37.7%) patients were nondisplaced. In male patients, fracture displacement was observed in 48 (81.4%) patients, while 11 (18.6%) were nondisplaced. The displacement in male patients was found to be significantly higher ($p = 0.021$). The distribution of fracture lines by sex is shown in Fig. 5.

Table 1 Patient demographics ($N = 120$)

Variable	
Age (mean ± SD) (Min–Max)	67,92 ± 17,44 (18–96)
Sex (n / %)	
Male	59 (49,17)
Female	61 (50,83)
Side of Injury (n / %)	
Left	65 (54,17)
Right	55 (45,83)
Fracture Mechanism (n / %)	
Falling	110 (91,67)
Traffic accident	9 (7,5)
Gunshot Injury	1 (0,83)
Garden Classification (n / %)	
1	8 (6,67)
2	26 (21,67)
3	61 (50,83)
4	25 (20,83)
Affected Zones (n / %)	
1	66 (55)
2	57 (47,5)
3	37 (30,83)
4	70 (58,33)
5	47 (39,17)
6	33 (27,5)

Table 2 The distribution of affected zones by age, sex, and fracture displacement

	Age		p	Sex		p	Displacement		p
	> =65	< 65		Man	Woman		No	Yes	
	N (%)	N (%)		N (%)	N (%)		N (%)	N (%)	
Zone 1			0.213			0.840			**0.002***
no	30 (40,54)	24 (52,17)		26 (44,07)	28 (45,9)		23 (67,65)	31 (36,05)	
yes	44 (59,46)	22 (47,83)		33 (55,93)	33 (54,1)		11 (32,35)	55 (63,95)	
Zone 2			**0.001***			**0.011***			0.641
no	49 (66,22)	14 (30,43)		24 (40,68)	39 (63,93)		19 (55,88)	44 (51,16)	
yes	25 (33,78)	32 (69,57)		35 (59,32)	22 (36,07)		15 (44,12)	42 (48,84)	
Zone 3			0.196			0.207			0.270
no	48 (64,86)	35 (76,09)		44 (74,58)	39 (63,93)		21 (61,76)	62 (72,09)	
yes	26 (35,14)	11 (23,91)		15 (25,42)	22 (36,07)		13 (38,24)	24 (27,91)	
Zone 4			0.485			0.877			**0.001***
no	29 (39,19)	21 (45,65)		25 (42,37)	25 (40,98)		22 (64,71)	28 (32,56)	
yes	45 (60,81)	25 (54,35)		34 (57,63)	36 (59,02)		12 (35,29)	58 (67,44)	
Zone 5			**0.002***			**0.001***			0.485
no	53 (71,62)	20 (43,48)		26 (44,07)	47 (77,05)		19 (55,88)	54 (62,79)	
yes	21 (28,38)	26 (56,52)		33 (55,93)	14 (22,95)		15 (44,12)	32 (37,21)	
Zone 6			0.051			0.084			0.229
no	49 (66,22)	38 (82,61)		47 (79,66)	40 (65,57)		22 (64,71)	65 (75,58)	
yes	25 (33,78)	8 (17,39)		12 (20,34)	21 (34,43)		12 (35,29)	21 (24,42)	
Displacement			**0.036***			**0.021***			
no	26 (35,14)	8 (17,39)		11 (18,64)	23 (37,7)				
yes	48 (64,86)	38 (82,61)		48 (81,36)	38 (62,3)				

*Indicates significant difference (P value < 0.05)

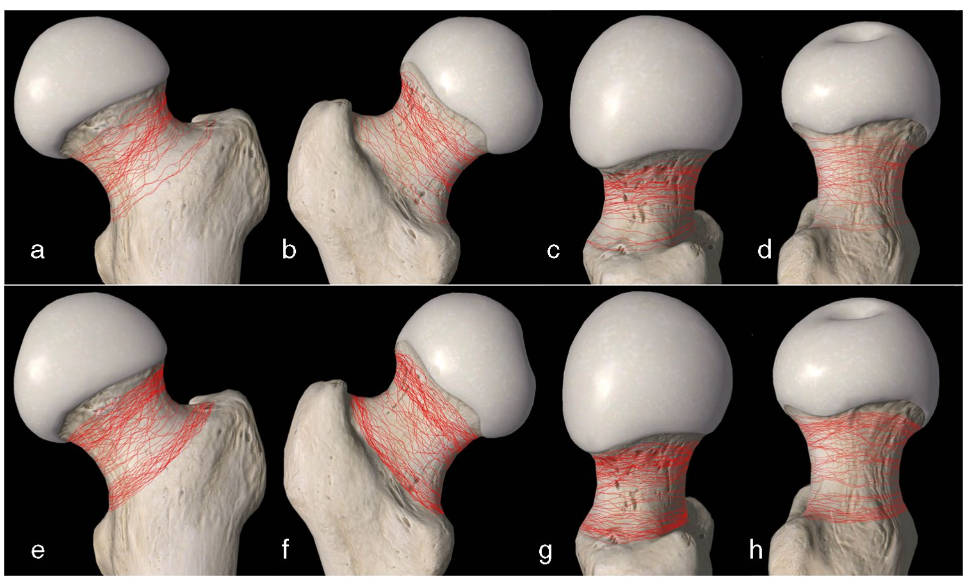


Fig. 4 The distribution of fracture lines in the patient group under 65 years of age; **a** anterior, **b** posterior, **c** superior, **d** inferior view. The distribution of fracture lines in the 65 and older groups; **d** anterior, **e** posterior, **f** superior, **g** inferior view

The distribution of affected fracture zones according to fracture displacement is given in Table 2. When the affected zones were examined according to the presence of displacement, the displacement in Zone 1 and Zone 4 was found to be statistically significantly higher (p = 0.002, p = 0.001). Additionally, no significant difference was observed in any zone in the comparison of the right and left femurs.

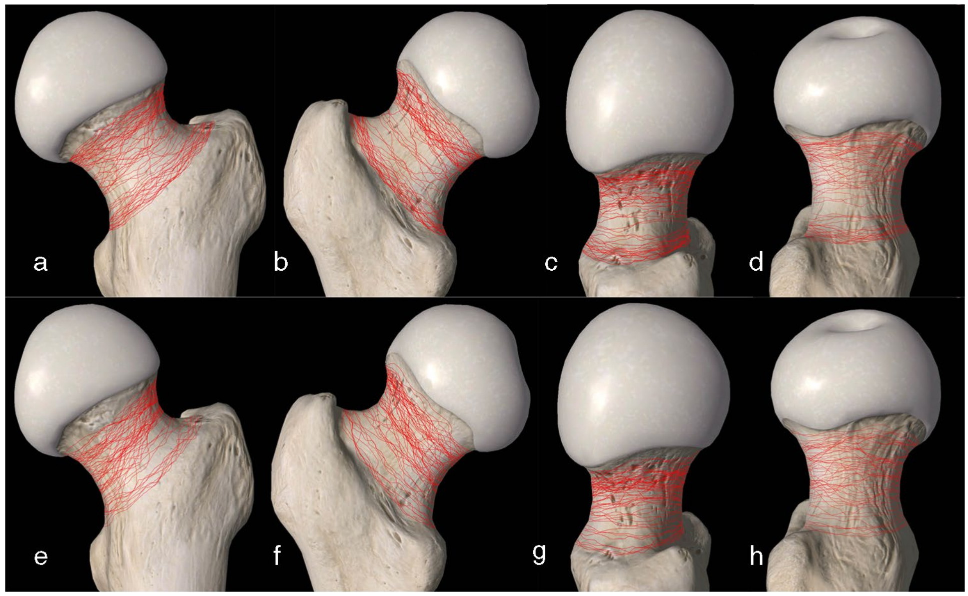


Fig. 5 The distribution of fracture lines in female patients; **a** anterior, **b** posterior, **c** superior, **d** inferior view. The distribution of fracture lines in male patients; **d** anterior, **e** posterior, **f** superior, **g** inferior view

Table 3 The distribution of the affected fracture zones

Affected Zones	*N*	%
1+4	29	24,16
3+6	25	20,83
2+5	16	13,33
1+2+4	13	10,83
1+2+4+5	9	7,5
1+4+5	8	6,66
2+4	4	3,33
2+3+5+6	4	3,33
1+2+3+4+5	3	2,5
2+3+6	2	1,66
1+5	1	0,83
1+2+5	1	0,83
2+3+5	1	0,83
2+4+5	1	0,83
2+3+4+5	1	0,83
1+2+4+5+6	1	0,83
1+2+3+4+5+6	1	0,83

The distribution of the affected fracture zones is given in Table 3.

Discussion

Hip fractures are an important health problem, the frequency of which is increasing with increasing life expectancy. According to a study by Cummings et al., while the annual number of hip fracture cases in the United States was 196,000 in 2000, this number is expected to be approximately 512,000 in 2040 [6]. When the whole world is considered, while it was 1,660,000 annually in the 1990s, it is expected to be approximately 6,260,000 by the year 2050 [1, 2].

A better understanding of the fracture is a very important factor affecting the success of treatment. The fracture mapping technique, on the other hand, is a method that has recently become common in practice and can affect treatment planning by providing a better understanding of the fracture. The mapping technique developed by Armitage and Cole et al. has been used for fractures in many fractures [7–13]. This technique was a visual way to show the fracture pattern. Some studies examine the distribution of fracture lines by dividing the anatomical regions into zones and examining the distribution of fractures according to the mechanism of the fracture [14, 15]. This study was planned to evaluate femoral neck fractures by mapping techniques for the first time.

We found significant variability in the morphology and the distribution pattern of fracture lines among the fractures. The fracture mapping technique was a good way to show the fracture pattern. In our study, it was seen that the most affected region was Zone 4 (%58,33). The least affected region was found to be Zone 6 (%27,5). In 45 (37.5%) of the patients, the fracture line was found to affect more than one zone in the anterior or posterior of the bone.

In 1976, Garden proposed an FNF classification based on traditional anterior–posterior plain films [16]. Although the Garden classification has some limitations, it is still one of the most used classifications today. One of the biggest limitations of the Garden classification is based on anterior–posterior (AP) radiography only. However, currently, femoral neck fractures are evaluated with multiple radiographs, such as lateral radiographs and traction radiographs.

The classification can distinguish most of the fracture patterns but cannot distinguish the different characteristics of each subtype, which needs to be complemented by 3D fracture mapping. Similarly, it has been reported that there are different types of fractures that are not defined in classical classification systems with the 3D mapping method in studies [14, 17].

In addition, advanced imaging techniques such as CT are widely used. Chen et al. reported in their study that fractures determined as Garden type 1 with standard radiographs can be interpreted as potential Garden type 2 after examination with CT [18]. In the study of J Stuart Merlin et al., the effect of CT on diagnosis and treatment in geriatric patients with femoral neck fracture was investigated. Accordingly, they showed that Garden classifications made by adding CT images to plain radiographs improved the results, but they reported that the treatment modality was not affected by the addition of CT images [19]. Again, according to the study of Zamora et al., after evaluation with CT in FNFs, interobserver agreement increased, and a treatment change rate of 21% was reported [20].

With the continuous development of CT, the description of fracture patterns has risen from two-dimensional to three-dimensional. Examination of 3D CT images has advantages over standard 2D CT images. In 2D tomography images, it is difficult to follow the broken fragment in every section. This can lead to a misunderstanding of the shape of the fracture and the complexity of the fracture. The 3D reconstruction technique demonstrated the different fracture patterns more clearly [21–23]. This technique allowed great convenience in fracture morphology. Since joint incongruity generally involves 3D displacement in multiple planes, only 3D CT can provide a direct demonstration of the fracture fragments. By using 3D reconstruction for fracture mapping, orthopaedic surgeons could see the shape of the fracture from any angle.

Xin Fu et al. examined Garden type 1 and type 2 femoral neck fractures by 3D modeling. According to their study, 3D modeling was suggested, and it was reported that these fractures could involve various degrees of displacement and were not undisplaced, stable fractures. The Garden classification for undisplaced femoral neck fractures has certain limitations [24]. In another study, Du et al. reported that 41 of 48 Garden-type 1 fractures examined with 3D imaging had potential rotation and displacement that could not be detected on standard radiographs. This study showed that the incidence of incomplete femoral neck fractures was low [25]. Similarly, in our study, rotational displacement that was not noticeable on standard radiographs was observed in some of the patients as a result of the 3D reconstruction procedure. In our study, we tried to obtain more reliable results by using 3D reconstruction on the CT scans of the patients to show the morphological characteristics of the FNFs.

When the literature is examined in terms of fracture displacement, according to the study of Murphy et al., the rate of displaced fractures was reported to be 74% [26]. According to the study by Talboys et al., 130 (49.4%) of 263 patients with femoral neck fractures were nondisplaced, and 133 (50.6%) were displaced [27]. Different rates of displacement have been reported in the literature. In our study, the rate of displaced fractures was 71.66%, while the rate of nondisplaced fractures was 28.33%. It was thought that the displacement rates, which were higher than some publications in the literature, may have occurred due to the evaluation of the fractures by 3D modeling. Rotational displacement that was not noticeable on standard radiographs was observed in some of the patients as a result of the 3D reconstruction. Similarly, Xin Fu et al. reported that displacement can be seen in fractures thought to be nondisplaced after 3D modeling [24]. In addition, the rate of fracture displacement was higher in males. It was thought that this may occur due to the development of fractures due to minor traumas as age progresses, especially in female patients due to osteoporosis.

Another limitation of the Garden classification is that it does not assess the anatomical localization of the fracture. However, there are studies in the literature reporting that anatomical localization affects the results [28]. In our study, to eliminate this limitation, the femoral neck region was divided into zones, and we tried to describe which zones the fracture passed through.

In our study, age had an effect on fracture type and fracture displacement. There was a significant difference in fracture type distribution and fracture displacement between patients aged 65 and over and those younger than 65 years of age. The fracture displacement rate was found to be lower in patients aged 65 and over. It also shows that the fracture lines are clustered in the subcapital and basocervical regions rather than transcervical fractures in patients aged 65 and over. Additionally, the displacement risk was found primarily on subcapital fractures.

When the results according to sex were examined, it was observed that fracture displacement was more common in male patients. In addition, transcervical region involvement was found to be significantly higher in male patients than in females. This may be related to the fact that female patients are at higher risk of fracture due to their higher mean age, and thus fractures may develop as a result of simple traumas.

The importance of pre-operative planning in orthopaedic surgery practice has been frequently emphasized in the literature. In a study by Black et al. in which the effect of CT imaging on pre-operative planning in malleolar fractures was examined, it was reported that the operation plan was changed in 24% of the cases [29]. Zheng et al., in which the effect of creating a 3D model on surgery in calcaneal fractures was investigated, found that the duration of surgery, the number of fluoroscopies, and blood loss were significantly lower in the model group. They also reported that better radiological results were obtained in this group [30]. On the other hand, the fracture mapping technique contributes to fracture classification, preoperative planning, determination and development of the appropriate surgical approach, appropriate implant selection, and development of new implants.

Our study was planned to reveal the relationship between demographic variables and fracture patterns. In this study, fracture mapping was performed in adult patients presenting with FNFs. In light of the data obtained from this study, we believe that the radiological features of femoral neck fractures can be better defined with the mapping technique. By providing a better understanding of the fracture, we think that the mapping of femoral neck fractures will contribute to the improvement of existing classification systems and the development of new ones, the development of different surgical approaches and reduction techniques, and the development of advanced implant technologies by providing a better understanding of the fracture. However, we believe that in the daily practice of orthopaedic surgery, the surgeon has a template in mind, and this template can help with the treatment planning stages.

Although our study is valuable because there is no mapping study for FNFs in the literature, it has some limitations. First, the study was designed to retrospectively include patients who applied to our clinic. Therefore, our findings should be evaluated within the limits of our research. Because the age distribution of male and female patients was not homogeneous in our study, the comparative data between male and female patients may have resulted in different results. Because our study consisted of patients who applied to our clinic within a certain period, we think that studies to be conducted in the broader period and with larger populations can provide more detailed information.

In conclusion, according to this study, in which femoral neck fracture mapping was performed, it was found that fracture displacement was less and transcervical region involvement was lower in patients aged 65 and over. It was observed that fracture displacement was less in female patients and that the transcervical region was less affected than in male patients. It was also found that the displacement rate was high in fractures of the subcapital region, and thus, the displacement risk was mostly in subcapital fractures.

Acknowledgements We thank Btech Innovation for making a 3D reconstruction of fractures. Thanks to 3D4Medical.

Author contribution All listed authors have contributed substantially to this work:

• Erman Öğümsöğütlü: First author of this article, curated the data, did fractures classification, wrote the original draft of the manuscript, and performed the methodology.

• Volkan Kılınçoğlu: Edited, and reviewed the manuscript, and carried out the project administration.

Funding This study was supported by Gaziantep University.

Data Availability Not applicable.

Declarations

Ethical review This study was approved by the Ethics Committee of Gaziantep University (Date: 23.03.2022 / No: 2022/121).

Disclosure No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

Conflict of interest The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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