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Three-Dimensional Computed Tomography (CT) Mapping of Intertrochanteric Fractures in Elderly Patients

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: The complex anatomy of the trochanter and the diversity in mechanisms of injury to it complicate intertrochanteric fracture patterns. Using digital technology, we created three-dimensional (3D) computed tomography (CT) mapping to show the relevant characteristics of intertrochanteric fractures in elderly patients.

Material/Methods: This was a retrospective analysis of a case series of closed intertrochanteric fractures in patients older than age 60 years who had sustained single-sided injuries less than 1 week previously. High-quality CT scans of the cases were used to create a 3D reconstruction fracture model, and fracture maps of the proximal femur were created by overlapping the fracture lines.

Results: A total of 115 patients were enrolled in this study, with mean age of 78 years (SD 7.98 years; range, 60 to 96 years). The essential features of the fracture lines were recorded in each case. Fracture maps revealed that the fracture lines were mainly concentrated in the area of the lesser and greater trochanter, intertrochanteric line, and intertrochanteric crest. As for fracture subtypes, results between patients were similar for Types A1 and A2 fractures, and differed for Type A3 fractures.

Conclusions: Detailed analysis of essential features of fracture lines revealed fracture fragments, some of which may be difficult to see using traditional imaging methods. Fracture maps composed of interindividual fracture lines revealed the relevant characteristics of intertrochanteric fractures in elderly patients. The resulting information about characteristics of distribution of fracture lines may be helpful in clinical practice.

MeSH Keywords: **Femoral Fractures • Imaging, Three-Dimensional • Maps**

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Background

The incidence of hip fractures increases with age, and as many as 50% of hip fractures in the elderly are intertrochanteric [1]. Patients with intertrochanteric fractures pose enormous challenges to the health care system because their injuries can lead to high rates of morbidity, disability, and mortality [2]. Given the growth of the aging population, intertrochanteric fractures may be one of the most important areas of research in modern medicine.

The complex anatomy of the hip often leads to difficulty in identifying fractures, and the diversity of fracture morphology makes classification of fracture more complicated. All of these factors contribute to the inability to accurately classify intertrochanteric fractures [3]. In 1949, to better describe the morphology of intertrochanteric fractures, Evans designed a classification method based on distribution of fracture lines and stability of fracture reduction [4]. Studies of the intertrochanteric fracture classifications later were published by Boyd [5] and Kyle et al. [6]. The AO classification method that is commonly used now was introduced in 1990 [7]. Several methods of classifying intertrochanteric fractures have been widely applied in clinical practice, but a way to identify intertrochanteric fractures in more detail and classify them is still needed.

Three-dimensional (3D) computed tomography (CT) scans may be helpful for more clearly identifying the distribution of fracture lines, and they have been widely used in orthopedics [8–10]. However, few studies have been designed of use of CT scans to map the features of intertrochanteric fractures. In this study, 3D fracture mapping technology was used to identify the morphological features of fracture fragments and explore distribution patterns of fracture lines, with the aim of more accurately classifying intertrochanteric fractures.

Material and Methods

Subjects

A retrospective search was performed for CT image data from elderly patients diagnosed with intertrochanteric fractures between January 2018 and June 2019. Patients were considered for subsequent analysis based on the inclusion and exclusion criteria listed in Table 1. High-quality CT scans of 115 intertrochanteric fractures were available for this study. The AO classification was used to identify isolated intertrochanteric fractures (including Types A1, A2, and A3) on radiographs and CT images. Classification was based on the consensus of 2 reviewers, and disagreements were resolved by discussion with the senior author.

Table 1. Study criteria.

Inclusion criteria
1. Closed intertrochanteric fractures that were displaced type A1, A2, or A3 according to the AO classification systems
2. Fracture <1 week old
3. Age ≥60 yr
4. Single side injured
5. Informed consent before data collection
6. Integrity assessment and quality control of computed tomography (CT) data were implemented before data processing
Exclusion criteria
1. Pathological fractures
2. Open fractures
3. Multiple trauma
4. Congenital or secondary bone diseases
5. Old hip joint and femur fracture or dislocation
6. Extremely disorganized or unidentifiable fracture lines
7. History of hip and femur surgery

3D fracture mapping technology

Raw data in the Digital Imaging and Communications in Medicine format were obtained by scanning the proximal femur with 64-channel CT scanning equipment (Siemens Somatom Sensation, Siemens, Erlangen, Germany). The parameters of the equipment were as follows: tube voltage, 120 kV; tube current, 200 mA; slice thickness, 1 mm; interlayer spacing, 0.5 mm. A 3D osseous model of the proximal femur was constructed based on the CT data, with an interactive medical imaging control system (Mimics 20.0; Materialise, Inc., Leuven, Belgium). The 3D fracture maps of the proximal femur were drawn with the method used by Xie et al. [11]. First, intertrochanteric fracture fragments were carefully reconstructed and relevant data were exported into 3-matic software (V9.0, Materialise, Inc., Leuven, Belgium). With the software, the reconstructed fragments were rotated, moved, and horizontally flipped to perfectly match the normal osseous model of the proximal femur. Then, smooth curves were drawn directly onto the surface of the template to approximate the fracture lines in each case. By overlapping all of the fracture lines, a 3D fracture map of the proximal femur was then created. Details of the 3D fracture mapping technology are described below and shown in Figure 1.

Osseous zone models

The proximal femur templates were artificially divided into 4 parts: the greater trochanter area (purple area), lesser trochanter

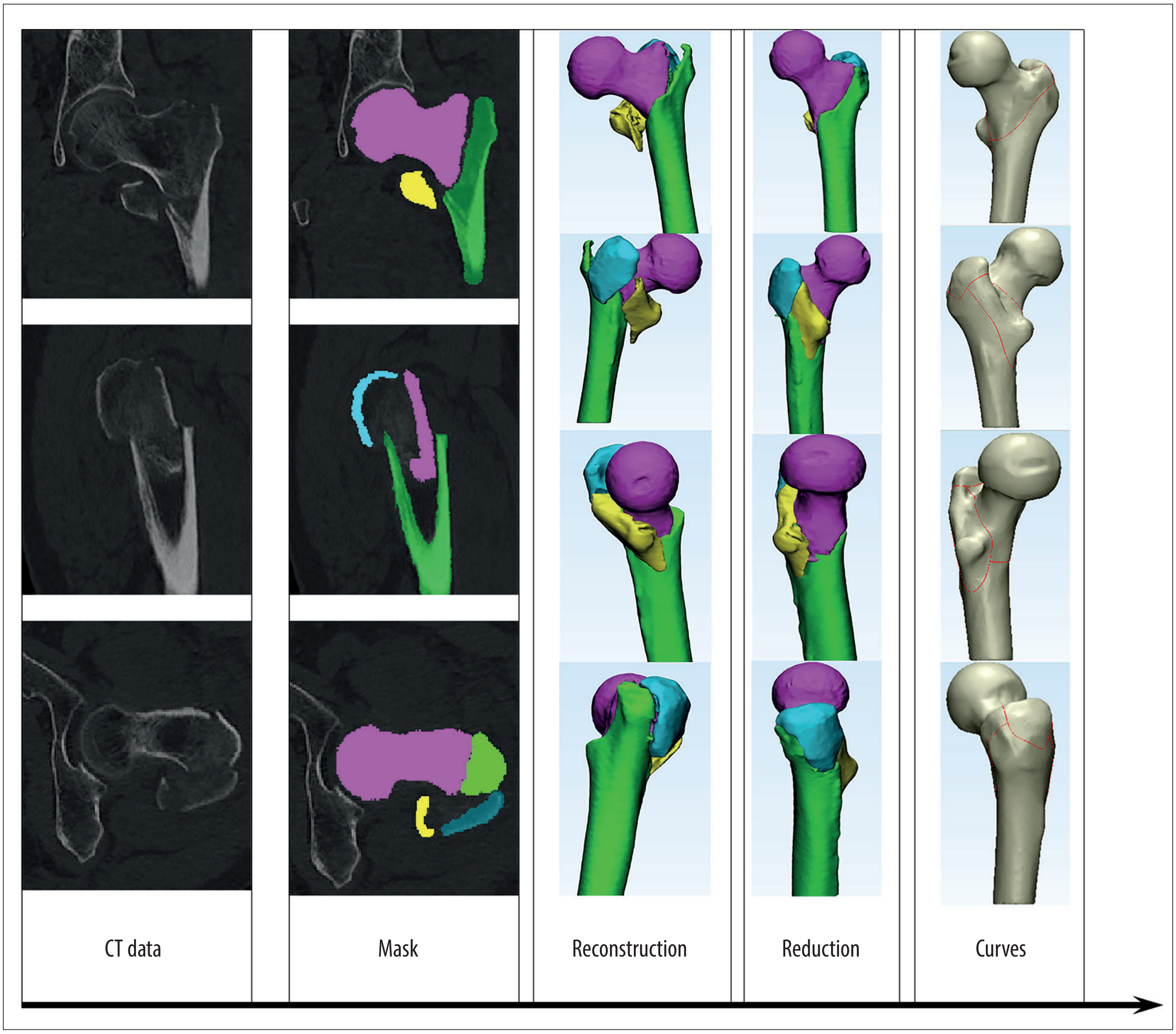

Figure 1. The processes of 3D fracture mapping technology. Raw CT data were obtained by scanning the proximal femur and the fracture fragments were then marked, reconstructed, reduced, and normalized to optimally match the standard template. Thereafter, smooth curves were drawn directly onto the surface of the model to delineate the fracture lines of each case.

area (reseda area), lesser trochanter lateral area (yellow area), and subtrochanteric area (wathet area). The templates were used to create osseous zone models, divided by several separate lines, for fracture pattern analysis (Figure 2). In the anteroposterior view (Figure 2A), 2 horizontal lines were made with the upper and lower dividing points of the lesser trochanter, respectively. Then, a vertical line was drawn from the lower dividing points of the lesser trochanter to the upper horizontal line. The upper boundary was the intertrochanteric line. In the posteroanterior view (Figure 2B), the upper boundary was the margin of the intertrochanteric crest and the other boundaries were consistent with the specific way the osseous zone was divided in the anteroposterior view. In the medial view (Figure 2C), horizontal lines were drawn for the upper and lower margins of the lesser trochanter, respectively. Next, a vertical line was drawn from the medial border of the lesser trochanter to the upper and lower horizontal lines. The medial edge of zone 9 was the base of the femoral neck. Viewing the model laterally (Figure 2D), the boundaries were the projections of the horizontal lines from the medial view. The lateral view then was divided into upper (zone 13), middle (zone 14), and lower (zone 15) parts.

Statistical analysis

Continuous variables were described using arithmetic means and standard deviations. Frequencies and percentages of categorical variables were measured. To analyze the fracture maps and relevant characterizations, a 3D map of each view was obtained. The essential features of the fracture lines in 4 views and their percentages were then summarized and analyzed.

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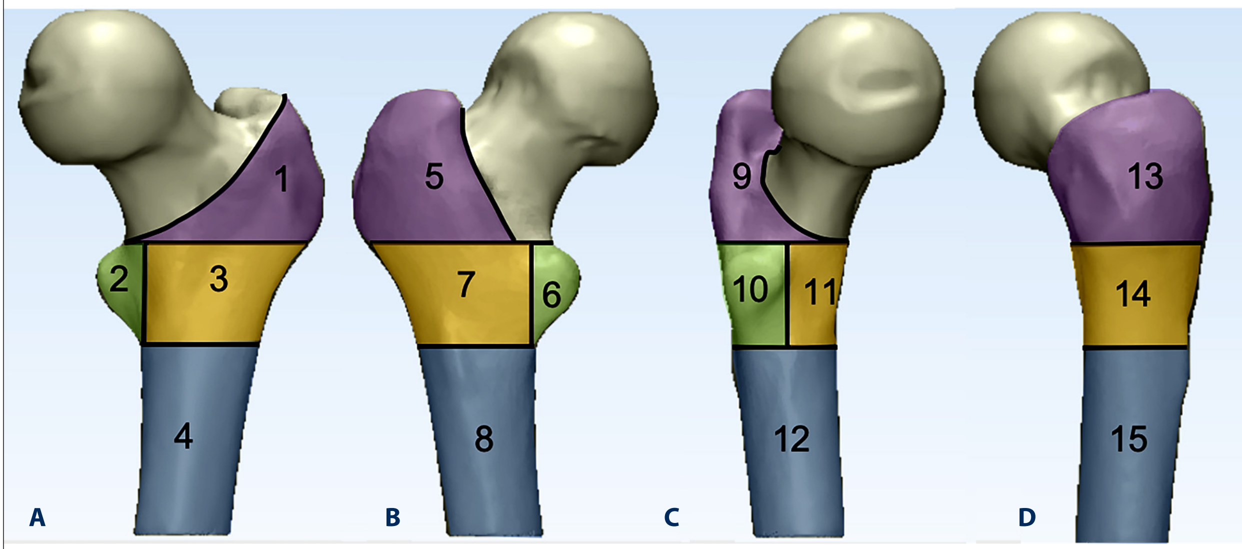

Figure 2. Osseous zone models. (**A**) Anteroposterior, (**B**) posteroanterior, (**C**) medial, medial, (**D**) medial. Several separate lines divide the proximal femur into 4 osseous zones: greater trochanter area (purple area), lesser trochanter area (reseda area), lesser trochanter lateral area (yellow area), subtrochanteric area (wathet area).

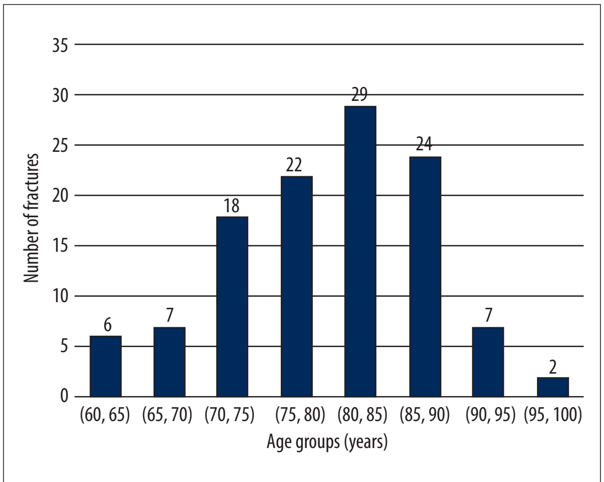

Figure 3. Histogram of age groups of all 115 elderly patients.

Results

Patient demographics and fracture classifications are summarized in Figure 3 and Table 2. The present study included validated data from CT scans of 115 trochanteric fractures, of which 43 (37.39%) were right-sided and 72 (62.61%) were left-sided. Of the patients, 37 were male (32.17%) and 78 were female (67.82%), with a mean age of 78 years (standard deviation 7.98 years; range, 60 to 96 years). Fractures were classified with the AO system [7]. As shown in Table 2, Type A2 fractures were the most common, followed by Types A3 and A1. As for the subtypes, Types A2.1 and A2.3 predominated.

Table 2. Patient demographics and fracture classification.

		n
Gender (%)		
Male		37 (32.17)
Female		78 (67.82)
Age [range, yrs]		78±7.98 [60–96]
Fracture side (%)		
Right		43 (37.39)
Left		72 (62.61)
AO classification (%)		
A1		12 (10.43)
	A1.1	5
	A1.2	5
	A1.3	2
A2		85 (73.91)
	A2.1	38
	A2.2	18
	A2.3	29
A3		18 (15.65)
	A3.1	4
	A3.2	3
	A3.3	11

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Table 3. Fracture distribution characteristics.

Group	Categories	n	Percentage (%)	Group	Categories	n	Percentage (%)
A	1	10	8.70	C	9	10	8.70
	3	2	1.74		9+10	8	6.96
	1+3	4	3.48		10+11	3	2.61
	2+3+4	1	0.87		11+12	3	2.61
	1+2+3+4	7	6.09		9+11	11	9.57
	1+2+3	89	77.39		9+10+11	28	24.35
	1+2	2	1.74		9+11+12	39	33.91
					9+10+11+12	13	11.30
B	None	7	6.09	D	None	2	1.74
	5	10	8.70		13	57	49.57
	7	3	2.61		14	1	0.87
	8	2	1.74		13+14	41	35.65
	5+6	3	2.61		14+15	9	7.83
	5+6+7	22	19.13		13+14+15	5	4.35
	5+7	14	12.17				
	5+7+8	47	40.87				
	5+6+7+8	7	6.09				

Categories represent the types of fracture lines, i.e., "1 + 2 + 3" represents a fracture line that passed through the first, second, and third zones concurrently while "1" represents a fracture line that only pass through the first zone and did not involve other zones. "None" indicates no fracture line.

When a fracture occurs, 1 or more fracture lines may be formed and the morphology of these fracture lines is varied. In Figure 4, the special osseous zone models were combined, with the aim of clarifying the basic distribution of these fracture lines.

In the anteroposterior view (Figure 4A), there were 7 types of fractures. Fracture lines that passed through zones 1, 2, and 3 concurrently were predominant (89/115; 77.39%). In the posteroanterior view (Figure 4B), there were 9 types of fractures. Fracture lines that passed through zones 5, 7, and 8 (47/115; 40.87%) and zones 5, 6, and 7 concurrently (22/115; 19.13%) were the 2 most common. In the medial view (Figure 4C), there were 8 types of fractures. Fracture lines that passed through zones 9, 11, and 12 and zones 9, 10, and 11 predominated (39/115 [33.91%] and 28/115 [24.35%], respectively). In the lateral view (Figure 4D), there were 6 types of fractures. Fracture lines that passed through zones 13 and 14 predominated (57/115 [49.57%] and 41/115 [35.65%], respectively). Table 3 lists the characteristics of the fracture lines in the 4 views, by region.

The fracture lines were mainly concentrated in the area of the greater trochanter, lesser trochanter, intertrochanteric line, and intertrochanteric crest (Figure 5). In the anteroposterior view, the fracture lines were mainly concentrated in 2 regions: the femoral tubercle, to which the iliofemoral ligament attaches, and the intertrochanteric line, which runs from the outside obliquely down to the inside of the intertrochanteric femur. These regions match the AO classification system definitions of Types A1 and A2 intertrochanteric fractures, respectively. The lines for Type A1 fractures were similar to those for Type A2, and it was only with Type A3 fractures that the lines fanned out from the intermediate region to the inferolateral shaft of the femur. In the posteroanterior view, the lines for Types A1 and A2 fractures also were mainly concentrated in the region of the intertrochanteric crest, running from the outside obliquely down to the inside of the of intertrochanteric femur. Trochanteric fractures often result in multiple fracture fragments in the intertrochanter, and the fracture lines affect a wide range of the proximal femur, but obvious regularities of distribution might not have been observed. In the medial view, the fracture lines were mainly concentrated at the base of the femoral neck and adjacent to the lesser trochanter. The medial side of the lesser trochanter had the most points at which fracture lines crossed, in the 11th zone. In the lateral view, most of the fracture lines involved the greater trochanter and ran from the anterior obliquely down to the posterior along the area where the gluteus medius muscle is attached. Lines in Type A3 fractures showed no obvious regularity, including the characteristics seen concurrently in Types A1 and

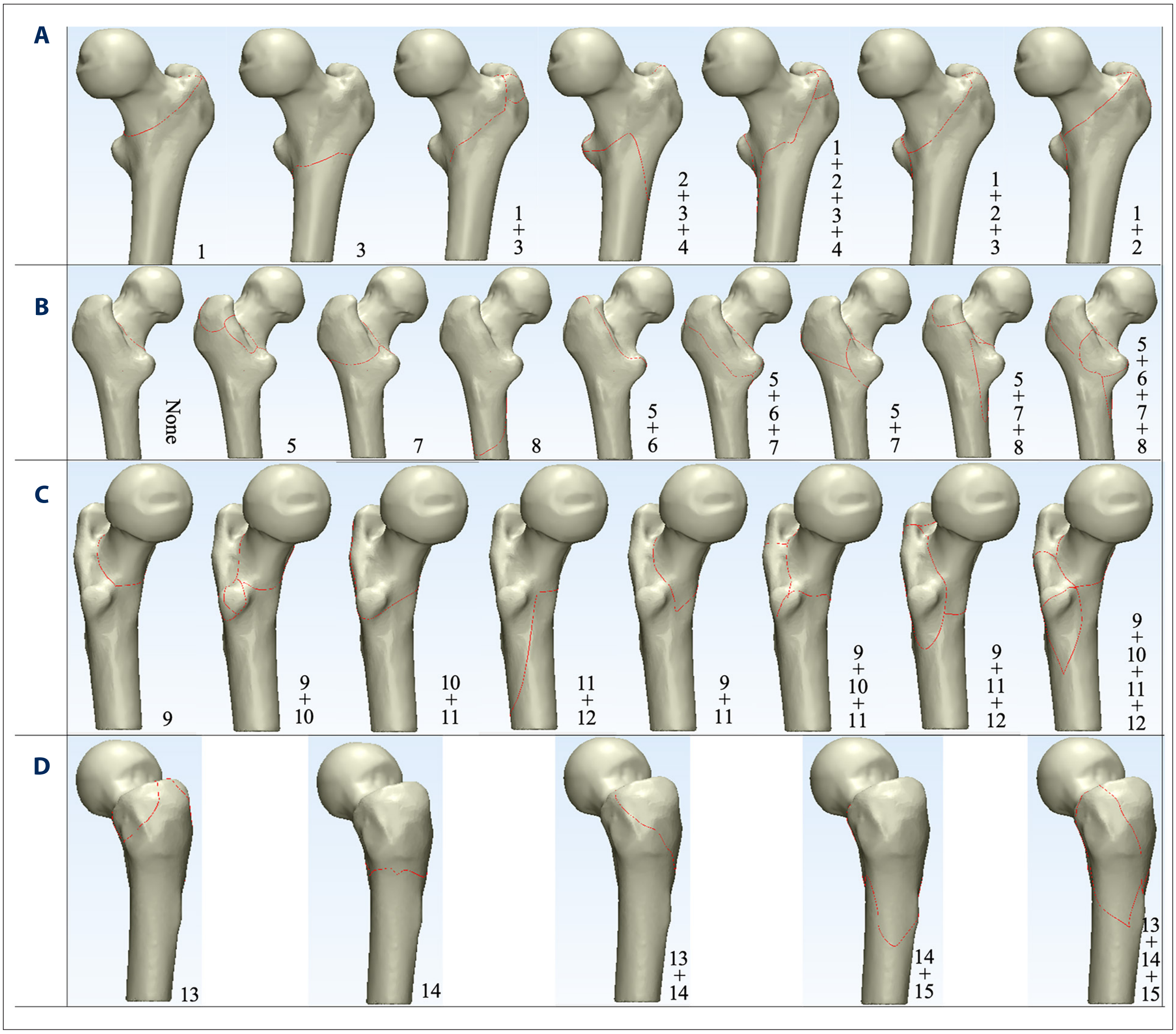

Figure 4. Classification of fracture lines. (**A**) Anteroposterior, (**B**) posteroanterior, (**C**) medial, (**D**) lateral. The fracture lines in each case were classified according to their region characteristics. For example, "1+2+3" indicates that a fracture line passed through the first, second, and third zones concurrently.

A2 fractures, and the affected subtrochanteric area was significantly increased. In addition to typical transverse and oblique fracture lines, there were also some irregular fracture lines, such as V, inverted V, and serrated types.

Discussion

Intertrochanteric fractures are one of the most common injuries in the elderly, as demonstrated by a significant body of research. The incidence of such fractures is expected to continue to rise as the aging population increases [12,13]. Osteoporosis is common in patients who are senile, and once they have hip fractures, their bones often can be broken by low-energy trauma, which results in a comminuted fracture [14]. Five factors that influence the stability of reconstructions after fracture fixation have been documented: bone quality, fragment geometry, fracture reduction quality, implant selection, and implant placement [15]. Chang et al., however, determined that adequate fracture reduction is always more important than the other factors [16]. Fang et al. showed that accurate reduction is of the utmost importance during treatment. That is logical because significantly reducing a fracture effectively restores maximal contact of the valuable bony buttress and returns the bone to its normal form, as has been described by Ito et al. [17–19]. Fracture mapping is an effective method of displaying fracture characteristics, which may have applications in research on many complex fractures, such as those of the plateau, humerus, and condyle [8,9]. The fracture spectrum it reveals can illustrate the characteristics of specific types of

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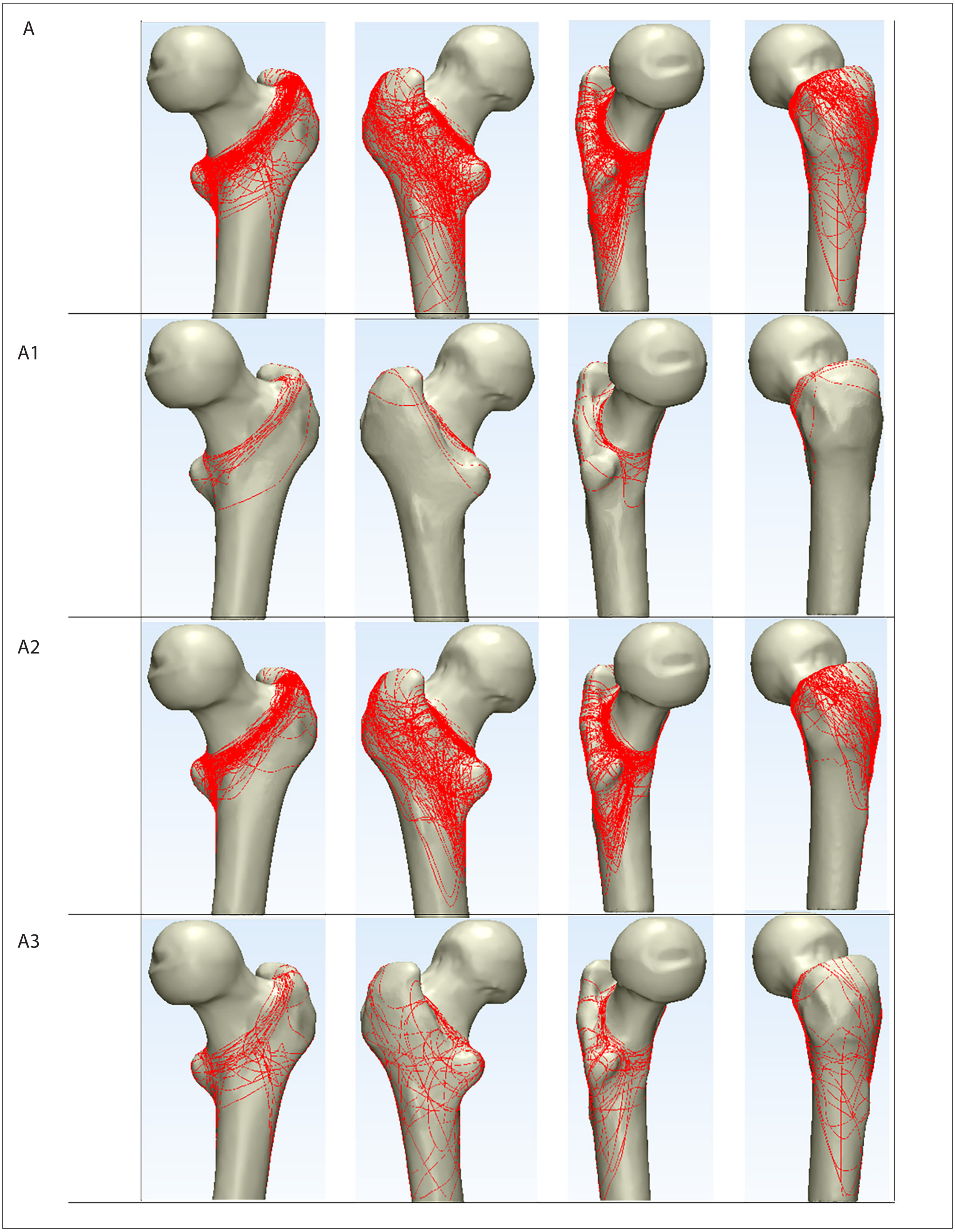

Figure 5. The 3D fracture mappings of intertrochanteric fractures in 4 views. The 115 elderly patients were classified based on the AO fracture classification system. "A" represented the pooled analysis of all fracture fragment, while expressions are for 3D fracture mappings of subtypes (including types A1, A2, and A3).

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fracture lines and how consistent they are, which is of great importance for describing fracture morphology.

In the anteroposterior view, the main fracture line is in the area where the iliofemoral ligament attaches to the intertrochanteric femur and in the zone of the intertrochanteric line, and may match the AO classification for Types A1 and A2 intertrochanteric fractures. However, there are still a small number of irregular fracture lines that do not conform to the traditional linear shape, and some are not in the concentrated area of fracture lines seen in Types A1 and A2 fractures in the anteroposterior view.

For example, a very small number of fracture lines in zones 2, 3, and 4 are an inverted "V" shape. The different types of fracture lines aside, it is not easy to perfectly reduce an anterior fracture [18,20] because the iliofemoral ligament restrains the anterior displacement of the femoral neck [21]. The lines in Type A3 fractures have the same features as in Type A1 and A2 fractures, but their range is larger in the lateral femur, affecting the femoral shaft.

In the posteroanterior view, a total of 9 fracture line patterns were found according to the division. The fracture lines are complex because of the constraint of the rotator muscles when during a fall, resulting in partial or total avulsion of the intertrochanteric crest. The multiple fracture fragments in the intertrochanteric crest are not well-represented on conventional X-rays, which easily can lead to misjudgment of fracture subtypes in the AO classification system. In 2016, Futamura et al. pointed out that there were 4 main types of fracture distribution characteristics in the posterior surface [21] and a more detailed division was outlined in that study. The pattern in Figure 4 clearly shows that there are various forms of avulsion, including none, a single line, or multiple fracture lines in the intertrochanteric crest that may or may not affect tuberosity.

In the medial view, the intersection points of fracture lines were mainly concentrated in the medial aspect of the lesser trochanter. The calcar femorale, an important structure near zone 11, is a dense, cancellous strut that stretches from the posterior aspects of the femoral neck to the posteromedial proximal femoral shaft. This structure plays an important role in providing mechanical support and transmission of stress from the femoral head to the proximal femur [22]. This shows the importance of zone 11. In addition, Snyckers et al. [23] theorized that satisfactory contact between the cortex and the posteromedial fracture fragments was of great importance for ensuring equal distribution of stress and preventing displacement of the femoral head and neck due to axial rotation, varus angulation, lateral translation, and anterior translation. In the AO classification, it also traditionally has been considered an important prognostic factor [24]. The part of the fracture lines that passes through the lesser trochanter to the posterior surface mostly involves the intertrochanteric crest. This part was concentrated in zone 10 and it may be related to traction from the iliopsoas muscle. Do et al. demonstrated the importance for stability of the lesser tuberosity [14].

In the lateral view, fracture lines were mostly concentrated in the area that had large tuberosity. Some data suggest that a broken greater trochanter is not always clearly visible on plain X-ray film [25]. However, the stability of intertrochanteric fractures can be influenced by a broken greater trochanter because of its effect on the lateral wall [24]. Therefore, a break in the greater trochanter that is misdiagnosed may give rise to negative health consequences. Sharma et al. concluded that formation of greater trochanter fragments may be due to the collision between the femoral neck and the greater trochanter [24]. As the size of a greater trochanter fragment increases, the available height of the lateral wall decreases [24]. May et al. confirmed that it was the effect of posterior soft tissue that revealed the role of the greater trochanter in affecting the stability and integrity of fracture fragments [26]. The distal ends of the gluteus medius and gluteus minimus are attached to the greater tuberosity, and pulling of them by abduction and internal rotation results in a larger trochanter fragment. Therefore, different injury mechanisms can lead to different fracture line morphology. In Figure 5, the fracture line was from the anterior obliquely downward to the posterior femur in Types A1 and A2 fracture. In Type A3 fractures, the area on the posterior side affected by the fracture was significantly larger than that on the anterior side. The integrity of the lateral wall is considered a significant prognostic factor in intertrochanteric fractures [27]. Thus, fracture line morphology in the lateral view should be well documented in clinical practice.

The limitations of this study should be mentioned. First, the process for drawing the fracture lines was subjective and the results are descriptive in nature. Therefore, the results may be somewhat biased. The sample size of only 115 cases was relatively small. Other segments should be analyzed in larger trials to reduce potential sampling errors. Second, we recorded the characteristics of the main fracture line in each case to form a fracture line map. However, the lines in some fractures, such as those were comminuted fractures and small in severe cases of collapse, were not well documented. Third, this study was performed in only a Chinese geriatric population. Differences in race and age may influence the composition of a fracture profile. Fourth, the mechanisms of injury were not analyzed in detail and differences in those mechanisms may affect the formation of fracture lines. Fifth, because boundaries of bone structures have not been clearly defined in the literature, the zones in this study were artificially determined, and different zones may have affected the results of the research.

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Conclusions

The classification systems for intertrochanteric fractures were initially developed based on anteroposterior radiographs as a way to understand fracture patterns and improve preoperative planning [4–7]. The approach used in this study differs from that in the previous papers. Detailed feature analysis of the fracture lines in each case and the resulting fracture map composed of the interindividual fracture lines revealed relevant characteristics of the intertrochanteric fractures.

In this study, the AO classification of the same fracture differed depending upon whether it was observed with X-ray or CT imaging. In some cases, the level of AO typing obtained with CT scanning is higher than that obtained with X-rays alone, which means that a fracture is sometimes found to be more serious on CT images than had been suspected with X-ray observation alone. CT scans also have advantages for differentiating AO subtypes. Traditional X-rays do not provide enough information with which to analyze the distribution characteristics of fracture fragments, and the fracture lines seen on X-rays often do not fit the actual fracture line distribution characteristics. A CT scan can clearly show local details of fracture lines, but it is difficult to use it to reasonably classify the morphology of a patient's fracture. Three-dimensional reconstruction can show the overall characteristics and displacement pattern of a fracture, and it has been used for some time to evaluate patterns of comminuted fractures. For intertrochanteric fractures, closed reduction often is performed and a C-arm machine is required to perform intraoperative fluoroscopy to obtain standard positive images as a reference for reduction. Preoperative 3D mapping can be used to clearly demonstrate the morphology of fracture fragments after anatomical reduction. The clear and accurate description of the location and morphological characteristics of fracture lines in the osseous zone shown in this study may have applications in clinical practice to intraoperative reduction, evaluation of its effects, and selection of therapeutic strategies. Further research is needed to evaluate whether the main intertrochanteric fracture features described in this study are reliable and whether differences in race and age of patients affects the distribution characteristics of fracture mapping.

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