Reunderstanding of Garden Type I Femoral Neck Fractures by 3-dimensional Reconstruction

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Abstract

Garden type I fractures include incomplete fractures and impacted fractures. With advances in scientific technology and medical treatment, certain deficiencies of the Garden classification have become apparent. The authors hypothesized that the incidence of incomplete femoral neck fractures was low and that impacted femoral neck fractures were not undisplaced and stable fractures. A new method was developed to precisely measure the spatial displacement of the femoral head in impacted femoral neck fractures. Between 2008 and 2011, nine hundred sixty-six patients with femoral neck fractures were treated, 48 of whom had Garden type I fractures, as seen on anteroposterior radiographs. Seven fractures were classified as incomplete on radiographs; however, after 3-dimensional reconstruction, 3 were classified as incomplete and 4 as complete fractures. Furthermore, the remaining 41 Garden I fractures that were classified as impacted on radiographs showed large spatial displacement on 3-dimensional reconstruction. The average rotational displacement of the femoral head was 19.29° ± 10.51°, and the average displacements of the femoral head center and the lowest point of the fovea capitis were 8.76 ± 4.45 and 14.39 ± 8.08 mm, respectively. This study showed that the incidence of incomplete femoral neck fractures was low. Impacted femoral neck fractures showed variable degrees of displacement and were not undisplaced, stable fractures. Garden classification for impacted femoral neck fractures has certain limitations. Impacted femoral neck fractures should be differentiated from Garden type I fractures so clinicians can select appropriate treatments for these fractures.

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The authors have no relevant financial relationships to disclose.

The authors thank the staff of the Department of Radiology, Tianjin Hospital, for help with computed tomography scans and radiographs.

This work was supported by the National Natural Science Foundation of China (Grant 11072021), (Grant 21205087), the Tianjin Health Bureau Science and Technology Foundation (No. 2011KJ117), and Wu Jie Ping Medical Foundation (No. 320.6750.11017).

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doi: 10.3928/01477447-20130523-31

Figure: Distribution diagram showing the labeling point in the proximal femur.
Fractures of the proximal femur can be considered an epidemic disease of the 21st century because of their increasing incidence. The annual worldwide incidence of hip fractures is approximately 1.7 million, and this figure is expected to reach 2.6 million by 2025 and 6.3 million by 2050. One-third of hip fractures occur in Asia, primarily in China. Femoral neck fractures are common, constituting 53% of all fractures of the proximal femur and 3.58% of all fractures throughout the body.

In 2004, the elderly population in China comprised 142 million people and accounted for a large proportion, approximately 11%, of the total Chinese population.

Femoral neck fractures are called unsolved fractures because they are associated with a high rate of femoral head necrosis and nonunion after osteosynthesis. Currently, no optimal guidelines exist for the surgical treatment of femoral neck fractures. The treatment of these fractures varies according to the patient’s age and fracture pattern. Displaced fractures are usually treated surgically by closed reduction and fixation or arthroplasty. For older patients with displaced fractures, many surgeons advocate prosthetic replacement. In contrast, the treatment of undisplaced femoral neck fractures remains controversial; specifically, it is unclear whether these fractures should be treated surgically or conservatively. The conservative treatment of undisplaced and impacted intracapsular fractures has been well described. Some authors advocate internal fixation with cancellous screws; however, a high rate of reoperation has been reported.

In 1961, Garden proposed a classification system for femoral neck fractures that has been widely used in which impacted fractures are classified as undisplaced and incomplete fractures. The Garden classification, although widely used, is highly controversial. For example, an undisplaced fracture is difficult to diagnose and differentiate from displaced fractures on radiographs, so different observers may diagnose various fracture types. The posterior angle of the femoral head in impacted fractures greatly affects the incidence of reoperation and avascular osteonecrosis of the femoral head after internal fixation. However, a reasonable and effective method for measuring the spatial displacement of the femoral head is currently unavailable.

The purpose of the current study was to precisely measure the spatial displacement of the femoral head in impacted femoral neck fractures by using 3-dimensional (3D) reconstruction and digital technology. These data were used to reevaluate the deficiency of the Garden classification for this type of fracture and to improve the diagnosis and treatment of these fractures in clinical practice.

**Materials and Methods**

This study involved 966 consecutive patients who were treated for femoral neck fractures in the Department of Orthopedics and Traumatology at Tianjin Hospital between June 2008 and November 2011. The authors included 405 men and 561 women, with an average age of 65 years (range, 17-93 years). The exclusion criteria were as follows: ipsilateral femoral shaft fracture or bilateral femoral neck fractures; pathological femoral neck fracture; congenital malformation; and previous femoral neck fracture. The current study was approved by the ethics committee of Tianjin Hospital.
and all patients signed an informed consent form prior to the experimentation.

The original preoperative anteroposterior radiographs that had been used for clinical decision making were obtained (Figure 1A). Each radiograph was numbered sequentially, and all patient identifiers were removed. The unlabeled radiographs were independently assessed by 3 observers: 2 senior orthopedic surgeons (X.F., Z.J.L.) and 1 consultant radiologist (T.Z.). The fractures were classified based on the original Garden classification using the original preoperative anteroposterior radiographs. To minimize bias related to different opinions regarding the classification system, the authors distributed Garden’s original description to all observers. For cases in which the individual assessments of all readers failed to reach an agreement, 2 traumatologists (X-L.M., H-F.Z.) made the final decision and determined the intraobserver reliability.

Computed tomography (CT) scans were obtained for the patients with type I fractures in the supine position using a Siemens Somatom Sensation 16 CT scanner (Siemens Healthcare, Forchheim, Germany). Axial CT scans from the superior margin of the acetabulum to the lesser trochanter were simultaneously obtained for the right and left femurs at 0.75-mm intervals (Figure 1A). The CT data were entered into the Mimics 10.01 medical imaging program (Materialise, Leuven, Belgium), which was used to create 3D reconstructions of both proximal femurs.

Using the mirror function in Mimics, a mirror 3D model of the fractured side was established. Next, the mirror model of the fractured femur was superimposed on the model of the contralateral normal femur, and a new mask was generated in the cross-sectional images in Mimics (Figure 1B, C). To measure the displacement and rotation of the impacted femoral neck fracture, 2 distinct and constant anatomical landmarks were selected: the femoral head center and the deepest point of the fovea of the femoral head. The center of the femoral head was determined and marked using computer-aided design software after a close-fit ball was generated at the edge of the femoral head. Two parameters were selected to describe the displacement of the impacted femoral neck fracture: the distance between the centers of the right and left femoral heads and the distance between the lowermost points of the foveae of the femoral heads. The displacements of the femoral fovea capitis (d1) and the femoral head center (d2) were used to evaluate the displacement of the impacted femoral neck fracture (Figure 1D). A line was drawn from the femoral head center to the deepest point of the fovea in each model, and the angle (α) of the intersection of the line in the fractured model with that in the intact model were used to measure the rotation of the impacted femoral neck fracture (Figure 1D).

All data were analyzed using SPSS version 13.0 software (SPSS, Inc, Chicago, IL).
Illinois). Means and standard deviations for the variables were obtained.

RESULTS

Assessments of the preoperative radiographs of the patients showed that there were 48 (4.97%) Garden type I (7 undisplaced and 41 impacted), 77 (7.97%) type II, 396 (41.0%) type III, and 445 (46.1%) type IV fractures. Of the 48 type I fractures, 21 involved the left femur and 27 involved the right femur; and 17 occurred in men and 31 occurred in women. The average age, height, and weight of these 48 patients was 53.6 years (range, 17-83 years), 168.5 cm (range, 156-188 cm), and 66.3 kg (range, 45-91 kg), respectively. Seven type I fractures were classified as incomplete on the anteroposterior radiographs; however, 3D reconstruction revealed that only 3 of these fractures were incomplete and the remaining 4 were complete fractures (Figure 2).

The remaining 41 type I fractures were classified as impacted on radiographs. However, these fractures showed greater spatial displacement and larger posterior angles for the femoral head on 3D reconstructed models than that measured on radiographs. Average rotational displacement (α) of the femoral head in patients with impacted fractures was 19.29°±10.51° (range, 4.41°-49.47°); 76% (31/41) of patients had a rotational displacement of 10° to 35°, and 37% (15/41) had a rotational displacement of more than 20°. The average displacements of the femoral head center and the lowest point of the fovea were 8.76±4.45 mm (range, 1.01-21.21 mm) and 14.39±8.08 mm (range, 2.23-39.48 mm), respectively. The displacement of the femoral head center exceeded 10 mm in 83% (34/41) of patients (Figures 3-5).

On average, the 3D reconstruction and measurement of undisplaced femoral neck fractures required 25±6 min (range, 16-33 min). Thus, it was a simple and practical method for the measurement of femoral neck fracture displacement.

DISCUSSION

Currently, impacted femoral neck fractures are classified as Garden type I fractures and are usually treated using closed reduction and internal fixation with cannulated screws.13,18 The incidences of nonunion, necrosis, and reoperation after the treatment of undisplaced femoral neck fractures are approximately 10%, 10% to 20%, and 10% to 20%, respectively.19,21

The development of internal fixation has not effectively reduced the incidence of osteonecrosis or reoperation.20 Therefore, accurate interpretation of the spatial displacement of the femoral head in seemingly undisplaced femoral neck fractures is essential to optimize treatment and reduce complications.16

In the current study, most patients with impacted femoral neck fractures had considerable rotational displacement of the femoral head and displacements of the femoral head center and fovea. Therefore, impacted femoral neck fractures were not undisplaced and stable. Many authors believe that it is worthwhile to confirm whether an impacted femoral neck fracture is stable due to mutual embedding and close combination of the fracture ends.8,22 If all impacted femoral neck fractures are considered undisplaced and stable, graded as Garden type I fractures and treated with closed reduction or conservative treatment instead of surgery as some authors have suggested,8,22,23 then they might result in irrevocable consequences, such as surgical failure, nonunion, and avascular necrosis of the femoral head.7,24 Therefore, it is imperative that orthopedists thoroughly understand the spatial displacement of impacted femoral neck fractures preoperatively so they can precisely correct the posterior angle of the femoral head, femoral neck anteverision angle, and colloidialphysical angle during surgery and strive for an anatomic diaphysis.

With the advanced developments in scientific technology and medical treatment, certain deficiencies of Garden classification have become apparent. Thomsen et al15 requested that 6 doctors classify femoral neck fractures in 96 patients; only 15% of the results were consistent, and a great deal of controversy was observed over the Garden type II and III fractures. Złowodziński et al25 surveyed 298 orthopedic surgeons and found that only 39% of them
believed that they could distinguish all 4 Garden types, whereas 96% felt that they could differentiate undisplaced (Garden types I/II) from displaced (Garden types III/IV) fractures. Beimers et al26 claimed that femoral neck fractures should simply be categorized as stable or unstable instead of using the unreliable Garden classification.

The Garden classification is based on 2-dimensional images, so it cannot truly represent the spatial displacement of femoral neck fractures.27 A retrospective study conducted by Conn and Parker6 on 375 patients with undisplaced femoral neck fractures treated with internal fixation revealed a positive correlation between the risk of nonunion and the degree of angular displacement of the femoral head on lateral radiographs. A significant and positive correlation was also seen between avascular necrosis and the posterior angle of the femoral head, as seen on anteroposterior radiographs (P=.017). They also found that the posterior angle affected the rate of nonunion.6 Palm et al16 followed up 113 patients with undisplaced femoral neck fractures for 1 year and assessed the posterior angle of the femoral head on lateral radiographs of the hip joint. The rate of failed internal fixation among patients with a posterior angle greater than 20° was 56% but was 13.6% in patients with a posterior angle less than 20°, further indicating the importance of the posterior angle of the femoral head.16 Therefore, a thorough understanding of the posterior angle and spatial displacement of the femoral head is critical for optimizing treatment plans and prognoses.10,28

Although it is relatively convenient to measure the degree of femoral displacement on lateral radiographs, it is difficult to obtain suitable standard anteroposterior or lateral radiographs,29 owing to the uncertainty of the projection center, angle, and distance and to the pain-related postural changes of these patients.30,31 Moreover, the diagnosis can be missed even if suitable radiographs are obtained. Chana et al32 recommended magnetic resonance imaging of undisplaced proximal femoral fractures to compensate for the misdiagnoses or missed diagnoses on plain radiographs. The posterior displacement of the femoral head is a 3D change, and radiographs cannot truly depict this spatial displacement because they are 2-dimensional.32 In addition, 3D reconstructed CT scans cannot completely isolate the femur, leading to difficulties in the measurement of the posterior angle and spatial displacement of the femoral head.33

Chen et al27 reported that femoral neck fractures that were identified as incomplete on radiographs were found to be complete fractures on CT scans. The current authors have found similar results: some of the Garden type I fractures judged to be incomplete on radiographs were found to be displaced complete fractures on 3D reconstruction. However, a few fractures were classified as incomplete on both radiographs and 3D reconstruction. Furthermore, Garden type I fractures judged to be impacted were found to be complete fractures with a relatively large displacement on 3D reconstruction. From the above, the current authors concluded that impacted, Garden type I fractures detected on radiographs can actually be unstable, displaced fractures. These findings can help to correctly identify this subcategory of type I fractures, making the Garden classification more accurate and facilitating the optimal treatment of unstable displaced Garden type I fractures.

The authors’ 3D reconstruction and digital measurement method can accurately depict the femoral head rotation and spatial displacement in patients with impacted femoral neck fractures. In addition, other parameters of spatial displacement due to fractures can be simultaneously and accurately measured. The authors’ method will enable orthopedists to formulate precise preoperative plans and offer reasonable treatments. Sufficient preparation can decrease the operation time, blood loss, and unnecessary complications.

**REFERENCES**


