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Research article

3D-CT imagistic for diagnosis assessment and orthopedic treatment of articular fractures with relevance for patient func-tional rehabilitation

Radu Baz [1], Dan-Marcel Iliescu [2], Bogdan Marian Caraban [3], Madalina Iliescu [4,*], Radu Andrei Baz [1], Bogdan Obada[5]

1 Department of Medical Imaging and Radiology, Faculty of Medicine, Ovidius University of Constanta, Romania
2 Department of Anatomy, Faculty of Medicine, Ovidius University of Constanta, Romania
3 Department of Plastic and Reconstructive Surgery, Faculty of Medicine, Ovidius University of Constanta, Romania
4 Department of Physical Medicine and Rehabilitation, Faculty of Medicine, Ovidius University of Constanta, Romania
5 Department of Orthopaedic and Traumatology, faculty of Medicine, Ovidius University of Constanta, Romania

* Correspondence: iliescumadalina@gmail.com
#All authors contributed equally in this researche

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Abstract: Background: The aim of the study was to determine the contribution of 3-dimensional computer tomography (3D-CT) in the diagnosis of the articular fractures compared with X-rays and computer tomography (CT), and to establish if 3D-CT can confirm or modify the preoperative plans. Methods: We have conducted a retrospective study between 2020 - 2022, 46 patients with articular fractures. We have asked 5 independent surgeons to make comparative analyses of the information required for a correct diagnosis and preoperative planning, obtained from X-ray, CT and 3D-CT. Each time, the surgeon was requested to categorize the fracture using specific classification systems and articulate their recommended treatment approach. Results: The study showed us the importance of 3D-CT to achieve a correct diagnosis for the articular fractures by ana-lyzing the discrepancies between X-ray, CT and 3D-CT, with direct influence upon the presurgical plan. In 37% of the cases, fracture lines were not apparent on X-rays but were visible on CT scans. However, in more than 27% of these instances, specific bone injuries, like central articular depression or unique split-comminution patterns, were not evident on standard CT scans but could be identified using 3D-CT scans. Conclusions: To establish the correct diagnosis and the proper therapeutical plan for the articular fractures, it is necessary to make a complete ra-diological evaluation, which consists of X-ray, CT and 3D-CT.

Keywords: diagnosis; treatment; computed tomography; tridimensional reconstruction; planning

Introduction

Surgical fracture treatment of irregularly shaped bones like the calcaneus, scapula, or scaphoid is demanding, starting with the need for high-quality imaging not only for classification of the fracture but also for planning the procedure: choosing which approach, which type of implant, identifying how many fragments, location of the key fragment. Plain radiographs are only able to provide some of this information. Therefore, computer tomography (CT) scans have become the standard for evaluating the criteria of complex fracture pathology [1,2].

Calcaneus fractures are the most common fractures of the hindfoot, and CT scans have been emphasized for evaluating this fracture since the early 1990s. Moreover, classification systems have been based on CT scans. For this reason, the 3-dimensional (3D) reconstruction of CT scans was proposed to improve the accuracy and precision of the evaluation of fracture pathology. With advancing technology in recent years, this has become available more readily [3,4,5].

The first step in treating acetabular fractures is identifying the correct fracture pattern on an anteroposterior (AP) pelvic radiograph. Letournel felt that most of the acetabular fracture patterns can be identified from the AP pelvis X-ray. Currently, plane films (AP pelvis and Judet views) and computed tomography (CT) are the modalities used to diagnose the correct acetabular fracture pattern. Two-dimensional and 3D CT reconstructions help in extrapolate the 2D image to 3 dimensions in the surgeon's brain. However, every effort should be made to classify the fracture pattern based on the AP pelvic and Judet views and the 3D CT reconstruction should be used for confirmation. This exercise forces the surgeon to critically analyze the radiographs and create his/her own 3D image in his/ her own brain. This process, if done for each fracture, is far more valuable to the surgeon intra-operatively than relying on the reconstruction. Drawing the fracture lines on either a 2D drawing of the pelvis or a 3D model is also extremely helpful to this process [6-9].

The aim of the study was to determine the contribution of 3D-CT examination in diagnosing of the articular fractures compared with X-rays and standard CT and to establish if the 3D-CT confirms or modifies the preoperative plans determined from plain film and CT.

2. Materials and Methods

We conducted a retrospective study between 2020 - 2022 on 46 patients with articular fractures: acetabulum (4), humeral head (8), tibial plateau (12), tibial pilon (10), talus (4), calcaneus (8). We have asked 5 independent surgeons (with at least 5 years of experience) to make comparative analyses of the information required for a correct diagnosis and preoperative planning, obtained first from X-ray, then CT and 3D-CT. The surgeon was asked each time to classify the fracture using specifical classification systems and how they would treat the fracture (Table 1). The parameters that were measured included the ability to detect intra-articular step and gap displacements, central articular depression, coronal plane fracture, the number of articular fragments, comminution, and associated injuries in the region.

2.

Initial X-ray assesment	**Diagnosis changes after**		**Treatment changes after**	
	CT	CT3D	CT	CT3D
Pelvic fractures (n=4)	25%	25%	25%	25%
Humeral head fractures (n=8)	50%	37%	25%	12.5%
Tibial plateau fractures (n=12)	33%	25%	25%	8%
Tibial pilon fractures (n=10)	30%	10%	20%	0
Talus fractures (n=4)	25%	25%	25%	0
Calcaneus fractures (n=8)	50%	37%	25%	25%

Table 1. Diagnosis and treatment changes after CT and CT3D.

Results

We have used AO classification for hip (Figure 1,2,3), humeral head (Figure 4) and tibial pilon fractures, Schatzker classification for tibial plateau fractures (Figure 5,6), Sander classification for calcaneus fractures (Figure 7) and Hawkins classification for talus fractures. The study showed us the importance of 3D-CT to achieve a correct diagnosis for the articular fractures by analyzing the discrepancies between X-ray, CT and 3D-CT, with direct influence upon the presurgical plan. In 37% of the cases, fracture lines were undetectable on X-rays but became visible on CT scans. Remarkably, in over 27% of these instances, specific bone abnormalities, such as central articular depression or distinctive split-comminution patterns, eluded detection on standard CT scans but were discernible through 3D-CT imaging.

Fig.1 Acetabular fracture, posterior wall on CT, number of fragments on CT3D.

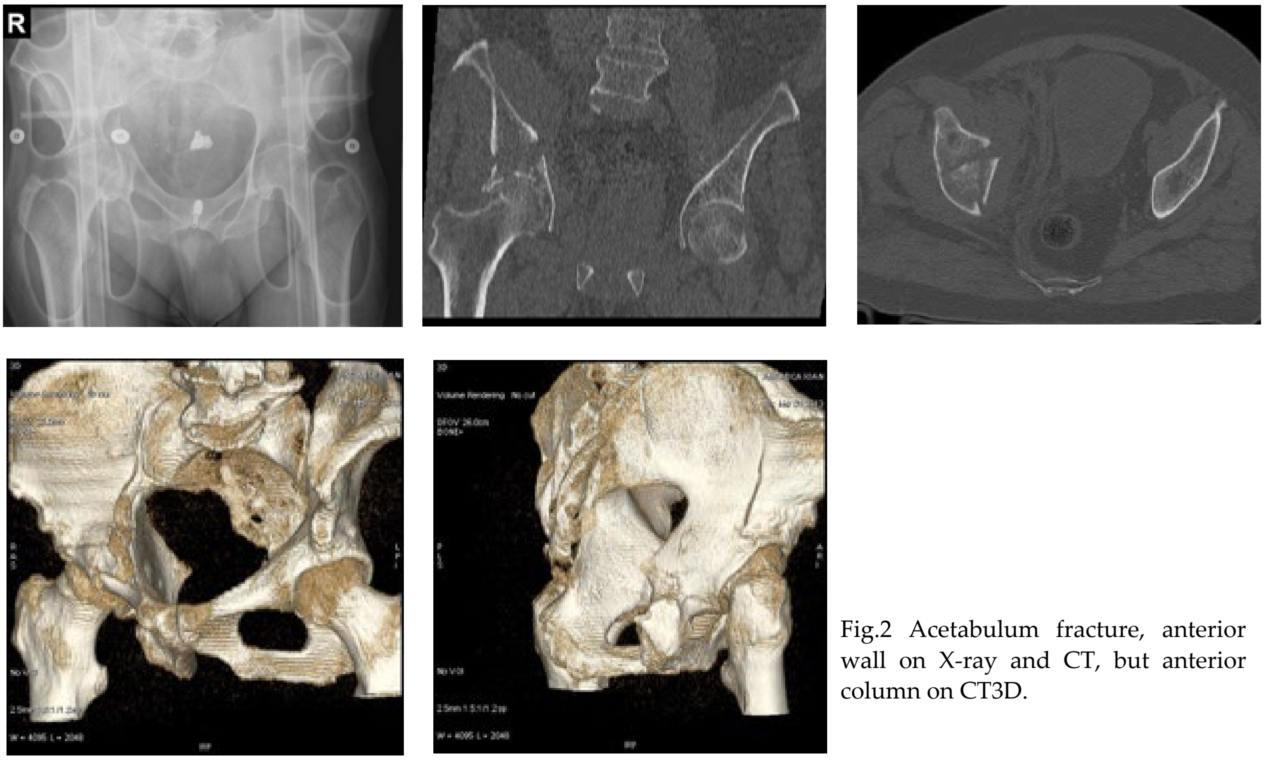

Fig.2 Acetabulum fracture, anterior wall on X-ray and CT, but anterior column on CT3D.

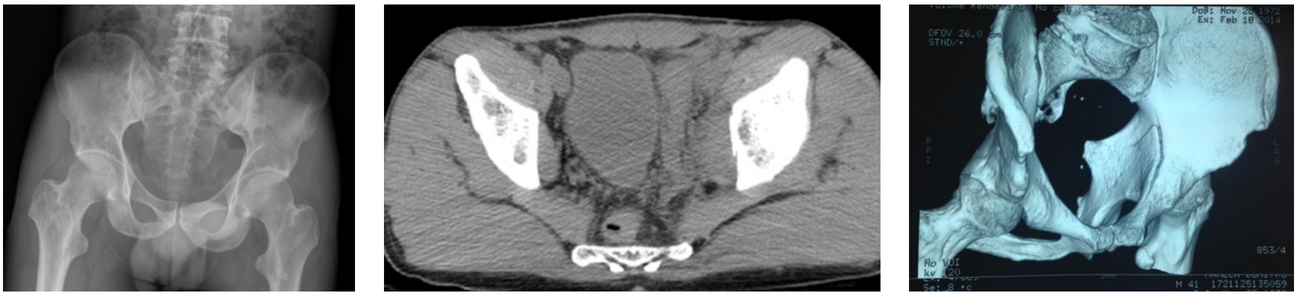

Fig.3 Acetabulum fracture, undiagnosed on X-ray and CT, but confirmed on CT3D.

Fig.4 Humeral head fracture-dislocation. Glenoid fracture confirmed on CT3D.

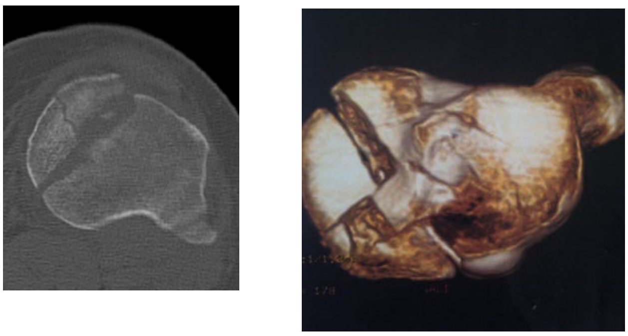

Fig.5 Schatzker I tibial plateau fracture on Xray, Schatzker IV on CT, displacement of comminuted fragments are clear seen on CT3D.

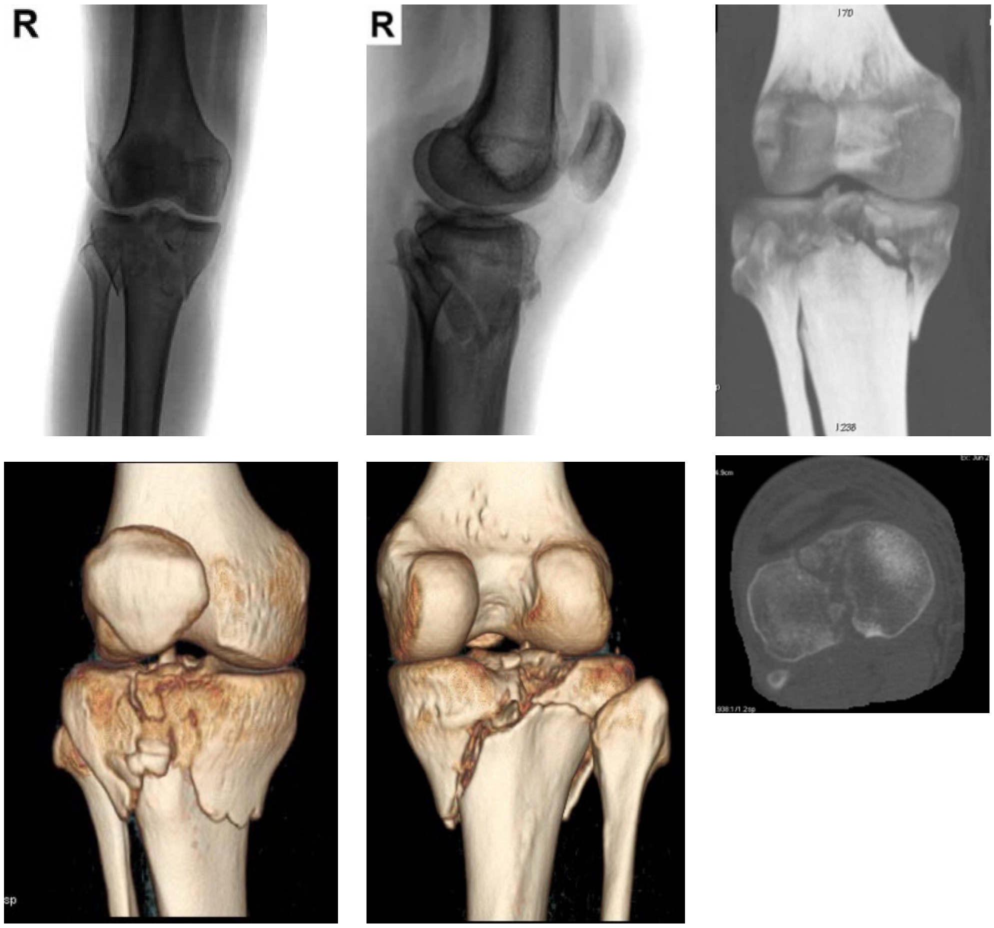

Fig.6 Schatzker V tibial plateau fracture, intraarticular gap and comminuted fragments are clear seen on CT3D.

3. Discussion

CT imaging has become an indispensable tool for the assessment and strategic planning of articular fracture treatments. Advances in multi-detector row CT technology and high-speed data processing in the emergency department allow rapid production of high-quality 2D and 3D images for interpretation. Our study indicates that the utilization of 3D imaging can enhance interobserver reliability in the classification of articular fractures while simultaneously reducing interpretation time for all groups of observers. It also indicates that only less experienced readers have a higher overall accuracy in classifying simple fracture patterns using 3D images than 2D images. The reported accuracy of CT in the classification of articular fractures could be more consistent. However, interpretation of 3D images has generally been reported to provide significantly higher accuracy and greater inter-observer reliability. Studies of orthopedic surgeons have revealed accuracy rates between 28 and 85% for 2D and between 52 and 92% for 3D images. The reported benefits of using 3D rather than 2D images differ among interpreters but mostly refer to fracture characterization and quality of the images [10,11].

Three-dimensional-assisted surgery consists in 3D imaging, 3D printing and patient-specific implants, which can be useful in the pre- and perioperative phases in acetabular fracture surgery. The added clinical value of 3D-assisted acetabular fracture surgery related to conventional surgery is currently debatable. Therefore, the aim of this paper was to assess whether 3D-assisted surgery enhances the surgical outcome and physical functioning. The results show a positive effect of 3D-assisted surgery on operation time, blood loss, fluoroscopy usage, and complication rates. Evidence of the improvement in physical functioning and fracture reduction is currently limited [12,13].

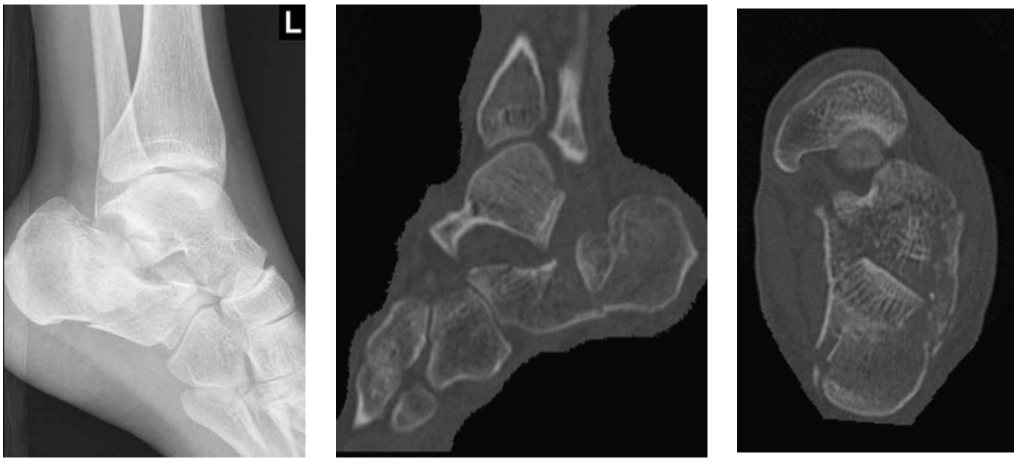

Fig.7 Type IIA fracture on CT, but IIIAC on CT3D with better information about the fragments and displacement.

Three-dimensional reconstruction of CT scans has the potential to enhance preoperative planning and surgical education. Although consideration of radiation exposure with CT scanning is important, reconstructing acquired data into 3 dimensions does not increase radiation dose, but it provides the ability to better facilitate education for medical students and residents and improves the learning curve for young orthopedic surgeons. The same technology is also used in computer-assisted surgery (CAS), allowing surgeons to develop forward planning, awareness of problems, flexible decision-making, and mental readiness [14-17].

Owing to their complex 3D anatomy and fracture morphology, acetabular and pelvic ring fractures are difficult to treat and are associated with a steep learning curve. The use of 3D CT scan reconstructions preoperatively with the combination of standard plain films and CT reconstructed 2D images has been shown to quicken the learning curve for inexperienced or-thopedic surgeons.

Proximal humerus fractures represent another area of the body where complex fractures can engage disagreements about fracture patterns and treatment plans. Studies analysing the use of 3D and 2D reconstruction CT scans of the proximal humerus have been mixed, with lack of interobserver agreement among fully trained orthopedic and trauma surgeons. Much like with acetabular fractures, the inclusion of 3D CT scans does not significantly enhance interobserver or intraobserver agreement among experienced surgeons. However, it does prove valuable in reducing the learning curve for evaluators with limited clinical experience [18,19].

Three-dimensional reconstruction imaging has been confirmed to be a valuable tool in acknowledging fracture morphology in complex periarticular injury. In looking at Hoffa fractures of the distal femur, obtaining a 3D map of the reconstructed fracture permitted analysis of location and frequency of fracture lines and areas of comminution. Three-dimensional reconstruction has also been applied to calcaneus fractures delineating the fracture morphology of tongue-type calcaneal fractures and appropriateness of percutaneous fixation and reduction maneuvers. CT scans have also had a significant impact on the initial assessment of patients with polytrauma [20].

Reduced surgical time, less intraoperative blood loss, and reduced intraoperative fluoroscopy usage in the 3D-assisted group could be argued by a more efficient surgery due to meticulous preoperative planning. Three-dimensional fracture visualization and 3D printing give more insight into the fracture characteristics. In addition, the use of 3D technology permits the planning of screw and implant positions. Due to optimized preparation, screw or implant malposition might be avoided. The use of pre-contoured or patient-specific implants could contribute to efficiency as well, because time-consuming intra-operative bending and fitting manoeuvres are redundant. Finally, the quality of the fracture reduction is noted as an important predictor for long-term native hip survivorship. Verbeek et al found that 3% of patients with an anatomic reduction (0–1 mm of residual displacement) on CT had conversion to total hip arthroplasty (THA) compared with 14% with an imperfect reduction (2–3 mm), and 36% with a poor reduction (>3 mm). In this review, small differences in fracture reduction were found between 3D-assisted and conventional surgery (3.1 ± 1.4 mm versus 3.7 ± 2.0 mm) [21,22].

Although magnetic resonance imaging is the usual modality for cross-sectional musculoskeletal imaging, the widespread availability, speed, and versatility of computed tomography (CT) present it as a mainstay of emergency room (ER) diagnostic imaging. Pelvic ring and acetabular fractures are caused by significant trauma secondary to either a motor vehicle accident or a high-velocity fall. These injuries are correlated with notable morbidity and mortality, both from the complications of pelvic ring fractures and from commonly associated injuries. The most commonly used classification of pelvic and acetabular fractures came to be on conventional radiographs that usually are enough to reveal the injury. However, because of the complexity of pelvic and acetabular fractures, precise spatial information is not easily shown by routine radiographs and in many cases details of fractures are not visible. Spiral CT lays out information that better characterise fractures and is viewed as complementary to x-rays for providing the spatial arrangement of fracture fragments. Spiral computed tomography is efficient for understanding complex fracture patterns, particularly when utilised with multi-planar reconstruction (MPR) either in 2D or 3D. Including MPR in routine pelvic imaging protocols can alter the management in a noteworthy number of cases. Subtle fractures, particularly those oriented in the axial plane, are proven on MPR or 3D volume-rendered images. Complex injuries can be better illustrated with 3D volume-rendered images, and complicated anatomic information regarding fracture fragments to be shown to orthopedic surgeons. The use of intravenous (i.v.) contrast material permits simultaneous evaluation of osseous and vascular structures within the affected area. Postoperative studies in patients with orthopedic hardware also benefit from volume-rendered imaging. Volume rendering eliminates most streak artifacts and reveals high-quality images on which the rapport among hardware, bones, and bone fragments are proven [23,24].

The current orthopedic literature supports the notion that inter and intra-observer reliability of complex fracture classifications improves with 3D CT. Furthermore, there seems to be a trend to use 3D CT in the diagnosis and decision-making process of other complex fractures, such as the distal radius. Previous studies have explored the use of 3D CT in calcaneus fractures. One study describes the utility of a 3D C-arm in intraoperative evaluation of the adequacy of reduction and implant positioning of operative treatment of calcaneus fractures. The other is a retrospective review that describes the findings of 3D CT of calcaneus fractures without systematically comparing them to 2D CT images. Both studies, in agreement with our present research, found that 3D CT scans were valuable for preoperative planning [25].

Three-dimensional reconstructions of CT scans have a number of advantages over standard 2D CT images. First, it can be difficult to observe a single fragment from one image to another on 2D images. Second, no single 2D scan reveals the articular surface well because different parts of the articular surface are shown in different slices. Finally, observers have to sort through the huge volume of information to interpret images. In our clinical practice and experience, the interpretation of 2D images can sometimes be confusing. Three-dimensional CT images may be easier for surgeons to interpret because they can promptly reveal better understanding of the articular surface, fracture complexity, and spatial relation of fragments. Several studies have proved the efectiveness of CT examinations with 3D reconstructions for tibial plateau fractures. However, no study, to our knowledge, has been designed to compare the agreement between classification systems of tibial plateau fractures among individual raters using 2D and 3D CT images [26,27].

The CT-3D technique affords a more accurate demonstration of the tibial plateau fractures than the plain-film examinations, allowing a precise classification, like for acetabular fractures. This classification gives rise to a better understanding of the tibial plateau fracture and, therefore, improves pre-operative plans. The CT-3D technique should not replace plain-film examinations of tibial plateau fractures. It is an excellent complementary technique in the precise diagnosis and classification of tibial plateau fractures and, due to its lower X-ray dose, should replace tomographic studies [28,29].

According to our data, the determination of the articular comminution and the number of articular fragments is better using three-dimensional computed tomography. These changes directly affected the grade of classification and the therapeutical plan regarding the surgical approach and anatomic reconstruction of the articular surfaces [28]. CT assessment led to a change in the planned therapeutic management in 27% of the cases compared to plain film, and 3D-CT assessment led to a change in 11% of the cases compared to CT.

4. Conclusions

To establish the correct diagnosis and the proper therapeutical plan for the articular fractures, it is necessary to make a complete radiological evaluation, which consists of X-ray, CT, and 3D-CT. Preoperative 3D-CT has brought a higher diagnosis accuracy concerning the fracture type and has made it easier to choose the proper therapeutical method. The potential disadvantage of three-dimensional imaging is the increased time and effort necessary for the reconstructed images, as well as the increased cost.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: All the data and materials are available upon requests from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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