Three-Dimensional CT Mapping of Intra-articular Calcaneal Fractures

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Research

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Abstract

Background: Intra-articular calcaneal fracture is a challenge for surgeons, which must be understood to provide optimal treatment. The aim of this study was to define the distribution of the primary fracture line and the secondary fracture line of intra-articular calcaneal fractures.

Methods: All X-rays and CT scans of intra-articular calcaneal fractures were collected from January 2014 to July 2020. According to the classification of Essex-Lopresti, these fractures were divided into tongue-fracture group and compression-fracture group. Construct 3D models of intra-articular calcaneal fractures in all patients, and record the location of all fracture lines, which were marked and integrated on the 3D model of intact calcaneus after virtual reduction. Heat mapping were created based on the occurrence frequency of fracture lines.

Results: A total of 171 patients with intra-articular calcaneal fractures were included in this study, 4 of whom were bilateral. There were 87 cases in the tongue-fracture group, 37 cases (42.5%) involved 4 anterior articular surface, 16 cases (18.4%) involved middle articular surface, and 52 cases (59.8%) involved calcanecuboid articular surface. There were 88 cases in the compression-fracture group, including 43 cases (48.9%) involving anterior articular surface, 21 cases (23.9%) involving middle articular surface, and 63 cases (71.6%) involving calcanecuboid articular surface.

Conclusion: The distribution of the primary fracture line and the secondary fracture line of intra-articular calcaneal fractures has a certain rule and correlation. Whether in tongue-fracture group or compression-fracture group, the fracture line is most often involves the calcanecuboid articular surface, followed by anterior articular surface, at least involves middlearticular surface. This study provides a theoretical basis for further exploration of calcaneal injury mechanism, construction of biomechanical model, and choice of surgical approach.

Introduction

Calcaneal fractures are the most common calcaneal fractures, of which about 75% are intra-articular calcaneal fractures. Conservative treatment of intra-articular calcaneal fracture usually leads to traumatic arthritis, arch collapse and abnormal axial alignment of metapedes, which makes it difficult for patients to walk and seriously affects life and work. With the extensive research on CT technology progress, internal fixation materials and biomechanics, surgical treatment of intra-articular calcaneal fractures has achieved better clinical efficacy [1–3], but there is still a certain risk of complications. Clarifying the pathological anatomical mechanism of calcaneal fractures can better guide the clinical practice and improve the surgical efficacy. At present, the distribution of fracture lines for some specific bones has been studied [4–7], but there is no three-dimensional(3D) reconstruction of intra-articular calcaneal fractures. So in this study we used three-dimensional(3D) mapping technology to described the intra-articular calcaneal fracture lines. We hope to enhance the understanding of intra-articular calcaneal fractures and aid the biomechanical modeling and clinical process by establishing a standard model.

Material And Methods

In this study, all CT assessments were performed using a 64-slice spiral computed graphic scanner(General Electric Company, American). Scanning parameters were set as follows: 120kV, 350mA, 0.625mm thickness, and 1s rotation time. Based on CT reconstruction, from January 2014 to July 2020, 171 Sanders II or III intra-articular calcaneal fractures patients' CT scan data were selected, including 4 bilateral, 62 right and 113 left. 151 males and 20 females(aged from 53 to 67 years, mean 61.5 years). All patients were divided into two groups according to Essex-Lopresti classification: tongue fracture and compression fracture. There were 87 cases in the tongue-fracture group and 88 cases in the compression fracture group. All patients signed the informed consent, and the study was approved by our hospital.

One healthy adult male volunteer was selected to make a CT scan of his right foot. Then we used Mimics to constructed the calcaneus 3D model with volunteer's CT scan data as a standard model. All patients' CT data were fed into the software(E-3D, Changsha,China) to reconstruct the 3D calcaneal fractures structure and a virtual reduction was performed for the separate fracture fragments. If the calcaneal fracture is left, the image is treated symmetrically. Using the software, the fracture lines were mapped to the standard model for each case, and the fracture lines of all cases were represented in the standard model to obtain the distribution map of the fracture lines. Then the fracture lines of all cases were superimposed to calculate the frequency of fracture lines in the 3D model. In heat maps, the relative fracture line distribution was represented as color following arbitrary units of measurement according to the frequency of fracture line appearing on calcaneal.

Results

In tongue-fracture group, according to the fracture line, there were 87 cases in the tongue-fracture group, 37 cases (42.5%) involved anterior articular surface, 16 cases (18.4%) involved middle articular surface, and 52 cases (59.8%) involved calcanecuboid articular surface. Among them, 13 cases were Sanders IIA (14.9%), 11 cases were type Sanders IIB(12.6%), 3 cases were type Sanders IIC (3.4%), 6 cases were type Sanders III AB (6.9%) and 4 cases were type Sanders IIIBC(4.6%). In compressed-fracture group, according to the fracture line, there were 88 cases in the compression fracture group, including 43 cases (48.9%) involving anterior articular surface, 21 cases (23.9%) involving middle articular surface, and 63 cases (71.6%) involving calcanecuboid articular surface. Among them ,33 cases were type Sanders IIA (37.5%), 35 cases were type Sanders IIB (39.8%), 7 cases were type Sanders IIC (8.0%), 9 cases were type Sanders III AB (10.2%), 2 cases were type Sanders AC (2.3%) and 2 cases were type Sanders IIIBC (2.3%) (Table 1).

Table 1
Proportion of Sanders Subtypes in Two Groups

	Sanders □A(%)	Sanders □B(%)	Sanders □C(%)	Sanders □AB(%)	Sanders □AC(%)	Sanders □BC(%)
Tongue Fracture	33.33	33.33	11.49	12.64	2.30	6.90
Compression Fracture	37.50	39.77	7.95	10.23	2.27	2.27

The lateral walls of the two groups were divided by fracture lines extending from the Gissane angle to the peroneal trochlea. The difference is that the secondary fracture line of the tongue fracture extends to the posterior calcaneal surface at the Gissane angle campared with the secondary line of compressed fracture extended between the calcaneal tuberosity and calcaneal cumulus (Fig .1 A□B).

The medial wall fracture line is was associated with the sagittal extension of the primary fracture lines and the secondary fracture lines, mainly distributed between medial process of calcaneal tuberosity and the lower surface of sustentaculum tali. Both groups' fracture lines were concentrated in front of medial process of calcaneal tuberosity (Fig .1 C□D).

In norma superor, the heat map of the two groups showed a large number of fracture lines concentrated at the Gissane angle. One fracture line was sent out from Gissane angle extending to the medial wall through the posterior articular surface of the calcaneus backwards and to the anterior articular surface or calcanecuboid articular surface forwards. Another fracture line extends from the Gissane angle to the lateral wall, while extending inward to the medial articular surface of the calcaneus and rarely involving the pitch process. The distribution of fracture lines of compression fractures was more intensive in anterior calcaneal and calcaneal cumulus than that in tongue fractures (Fig .1 E□F).

In norma inferior, most of fracture lines were located on the medial and lateral sides of anterior tubercle of calcaneus. There was a concentrated distribution in front of the anterior tubercle of calcaneus (Fig .1 G□H).

Discussion

The anatomical structure of the calcaneus is irregular, and about 50% of the weight bearing of the foot is accomplished through the calcaneus. The anatomical relationship between calcaneus, talus and cuboid is the basis of hindfoot joint movement, which plays an important role in maintaining normal gait. The injury mechanism of intra-articular calcaneal fracture is also complex, and the shape of fragment is different, which is mainly related to the direction of impulse force, the position of foot and muscle tension at the time of injury [8]. According to the distribution characteristics of fracture line, there are many types of intra-articular calcaneal fractures and the most commonly used clinical classification is the Essex-Lopresti classification and the Sanders classification. But no matter what the classification method, the characteristics of calcaneal fracture can not be fully interpreted. Previous studies on the characteristics of calcaneal fractures were limited to the observation and description of the fracture model after 3D reconstruction, the integration of fracture lines in this study can more intuitively discover the distribution characteristics of fracture lines in 3D heat map models. This is helpful to further explore the mechanism of intra-articular calcaneal fracture.

The intra-articular calcaneal fracture is usually thought to be caused by shear and vertical force, but there is controversy about the primary fracture line. Some scholars believe that the primary fracture line of calcaneal fracture is only produced by the shear force of the lateral talar process acting on the Gissane angle, which divides calcaneal into anteromedial and anterolateral fracture blocks, and the rest are secondary fracture lines [2, 3]. However, Carr thought that there was another primary fracture line, which was produced by vertical force, and the calcaneus is divided into two parts. For the injury with relatively low violence, the two primary fracture lines can exist separately. And he proposed that in coronal plane, primary fracture line gradually transformed into a "Y-shaped" secondary fracture line on the lateral wall of the calcaneus extending its two “arms” to the anterior calcaneus process and the calcaneal tuberosity respectively [9, 10]. In this study, we also believe that there are two primary fracture lines sometimes, but the difference is that both tongue and compression fracture lines extend directly to the peroneal trochlea and no secondary fracture line was formed, which is the reason of peroneal tendon compresses to the fracture end when the lateral wall of calcaneus is a burst fracture.

In addition, we believe that the production of secondary fracture lines is closely related to the internal structure of the calcaneus. Bone cortex can carry its own load as well as interact with trabeculae to complete the conduction of force. In this study, the direction of secondary fracture line of medial and lateral wall is approximately the same as that of trabecular arrangement of tension bone after calcaneal. Athavale et al [11] found that the Posterior compression trabeculae were fan-shaped, and the secondary fracture line of tongue fracture is located where trabecular arrangement is more compact than other parts(Fig .3 A). Therefore, we believe that the change of mechanical structure at the junction of different lamellar layers is easy to lead to fracture. Additionally, the trabeculae are sparsely distributed in the central triangle region of the anterior calcaneus. When the facies articularis calcanearis posterior collapses, the triangular region is compressed, which causes comminuted fractures of the anterior calcaneus (Fig. 3F). Because the cortex of medial wall and sustentaculum tali of calcaneus are thick, they can carry more stress and hard to fracture. However, the tendon attachments can also makes the cortex bone thickened, and the secondary fracture line is rarely involved because of the long-term traction of the tendon (Fig .3 G、H).

Because of the diversity of the mechanism of calcaneal fracture injury, the construction of fracture model is relatively difficult. If it is constructed by axial violence, the size and direction of violence are difficult to control, which will lead to the difference between the models. Thordarson et al [12] used micro-saw to cut out 6.5 mm grooves separately on the medial, lateral and posterior articular surfaces of the calcaneus, and produce axial pressure at the same time to construct a compression fracture model. But the fracture model of this scheme is relatively simple and has a large gap compared with clinical practice. Lin et al

[13] proposed the construction of compression fracture model by osteotomy and incarceration. Although this method is a relatively recognized modeling method and many scholars also use this model to study calcaneal biomechanics [14, 15], it is still different from clinical calcaneal 148intra-articular fracture. Therefore, we describe the distribution of heat map of tongue fracture and compression fracture, which provides the basis for the accurate construction of fracture model and facilitates the improvement of surgical technology and 3-D fracture maps may prove useful in facilitating improved communication and surgical understanding of fixation concepts to better address the complex articular injuries.

In addition to restoring the length, height and width of the calcaneus, the current treatment of intra-articular calcaneal fractures pays more and more attention to correcting calcaneal force line and reconstruction of articular surfaces. However, The subtalar joint is a very complex structure with three articular surfaces. The functions of the anterior, middle and posterior articular surfaces complement each other. Wagner [16] found that although the total area of the anterior and middle articular surfaces was only 31% of the posterior articular surfaces, they bear the 63.3% weight on which the posterior articular surface loaded. Therefore, poor reconstruction of anterior and middle articular surfaces increases the risk of traumatic arthritis. Silhanek et al [2] made a study of intraarticular calcaneal fracture lines found that about 39% of the patients with fractures involving the anterior and medial surfaces. Miric and Patterson [8] found that 27% of intra-articular calcaneal fractures involved the anterior articular surface and 8% was the middle articular surface, which was significantly lower than the results of this study. Because it's difficult to accurately determine the involvement of the anterior and middle articular surfaces through two-dimensional CT images, and it's more intuitive to use three-dimensional reconstruction CT [17]. In addition, according to previous research reports, fractures involving the calcaneocuboid articular surface accounts for 33%-76% of intra-articular calcaneal fracture [18]. Ebraheim [19] also suggested that compression fractures are more likely to involve calcaneocuboid joints than tongue fractures. In this study, about 59.8% of the tongue fractures involved the calcaneal joint, and compression fractures are up to 71.6%, which is in accordance with previous research results. We believe that for displaced intra-articular calcaneal fractures involving the calcaneocuboid joint, attention should be paid to the reconstruction of the articular surface and a lateral “L” approach is recommended. If we simply use the tarsal sinus approach to perform a “three-point fixation”, there is more likely to result in calcaneocuboid arthritis and even subluxation of calcaneocuboid joint occurs postoperatively.

There are also some shortcomings in this study. The patients in this study are both Sanders II and III intra-articular calcaneal fractures because the articular surface of the Sanders IV fracture was broken seriously and it is difficult to use software for virtual reconstruction. So it was not included in this study, which may have a certain extent effect on the fracture line heat map. Secondly, this study is a descriptive research and there may be some subjectivity.

In conclusion, although the injury mechanism of calcaneal intraarticular fracture is complex and different injury mechanisms can produce different fracture types, the distribution of primary fracture line and secondary fracture line is still regular and relevant, which provides a theoretical basis for further exploration of calcaneal injury mechanism, construction of biomechanical model, and choice of surgical approach.

Declarations

Ethics approval and consent to participate:

All patients which were included in the present study were gave written informed consent for their data in this study. All data was obtained from the clinical and radiograph records. This study was approved by the Institutional Review Board/Ethics Committee of the Shanghai Tongji Hospital.

Consent for publication:

Not applicable.

Availability of data and materials:

All data generated or analysed during this study are included in this published article.

Competing interests:

The authors declare that they have no competing interests.

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Figures

Figure 2 and 3 are not available with this version.

Figures

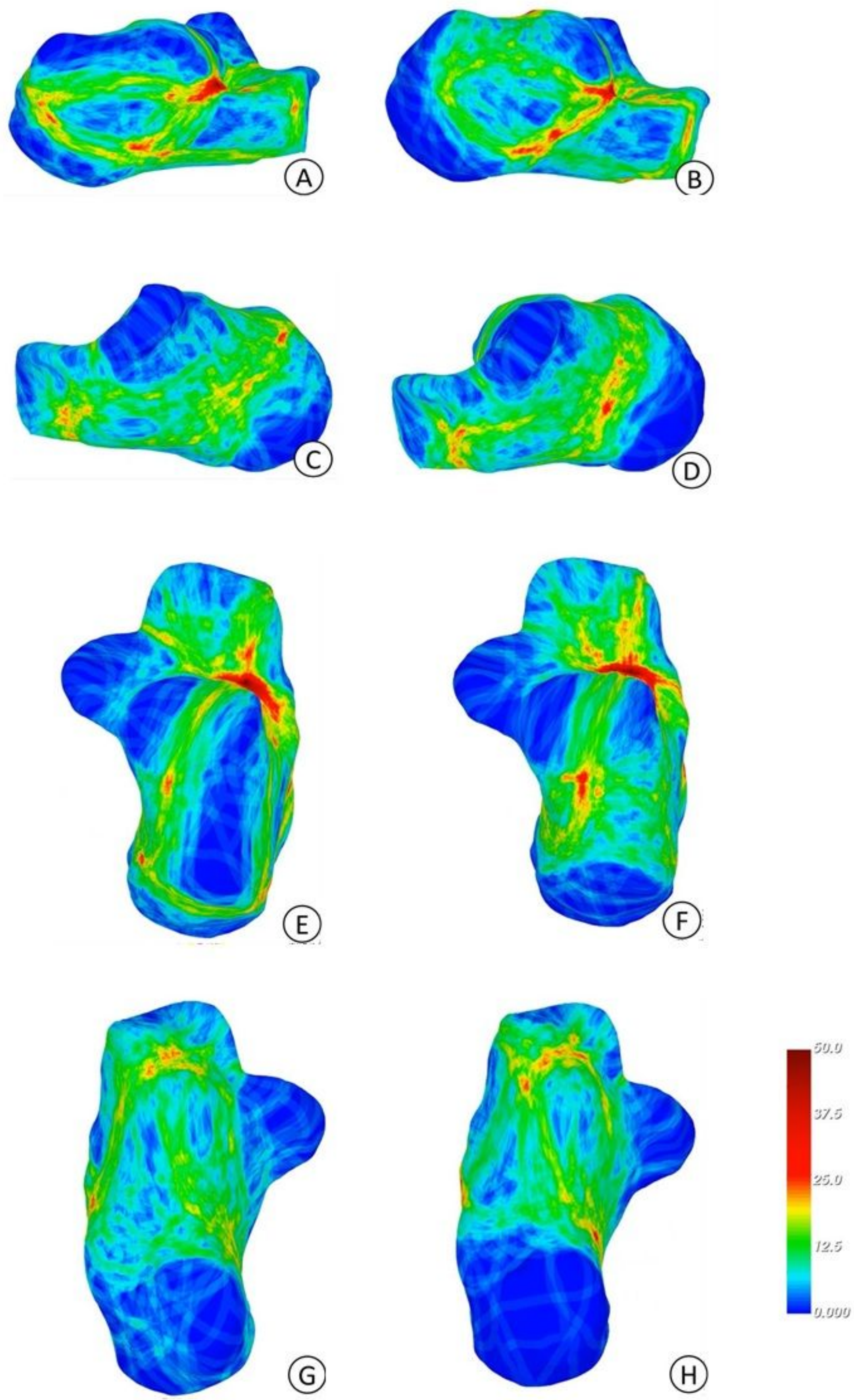

Figure 1

The heat map distribution of tongue fracture and compression fracture : A and B are lateral view; C and D are medial view of compression fracture; E and F are norma superor; G and H are norma inferior.