Definition of a safe zone for screw fixation of posterior talar process fracture by 3-dimensional technology

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Abstract

Background: Percutaneous screw fixation can provide stable fixation with a minimally invasive surgical technique for posterior talar process fracture.

Objectives: The purpose of this study was to investigate the optimal posterior screw placement and the geometry of safe zone for screw insertion in the posterior talar process by analyzing with 3-dimensional (3D) technology.

Methods: 100 adult feet computed tomography (CT) scans were evaluated. CT data were imported into Materiaise's interactive medical image control system (MIMICS) 18.01 software for 3-dimensional reconstruction. Two 3.0mm-diameter screws were simulated from the anterior to posterior position for posterior talar process. The morphology parameters of posterior talar process were also quantitatively measured. The safe zone and the length and entry point of screw were defined.

Results: The optimal entry point of screw for posterior talar process fracture was lateral tubercle from the posterior to anterior position. The safe zone of medial tubercle entry point was smaller in lateral tubercle. These gender-specific measurements were all significant (P<.001).

Conclusions: The predefined zone with computer-assisted 3D techniques for the most frequently positioned percutaneous screws may aid in preoperative planning, shorten the operation time and reduce the incidence of surgical complications.

Abbreviations: 3D = 3-dimensional, CAD = computer-aided design, CT = computed tomography, MIMICS = Materiaise’s interactive medical image control system, ORIF = open reduction and internal fixation.

Keywords: percutaneous fixation, posterior talar process, safe zone, screw, 3-dimensional technology

1. Introduction

The posterior talar process is comprised of medial and lateral tubercles which serve as attachments for the posterior talotibial and talofibular ligaments, respectively. Posterior talar fracture usually involves an isolated fracture of either medial or lateral tubercle and simultaneous fracture of the medial and lateral tubercles (entire posterior process fracture).\textsuperscript{1,2} Most reports were fracture of posterior talar process associated with subtalar dislocation,\textsuperscript{3–8} and recommended early open reduction and internal fixation (ORIF). However, ORIF is difficult because of close to the ankle joint, subtalar joint, neurovascular bundle, and flexor hallucis longus tendon. The best surgical approach is still in controversy. Previous reports have described that ORIF treatment leads to a different outcome.\textsuperscript{9} The minimally invasive approach for fracture was described which is an attractive alternative to major open procedures, especially in the patients who have multiple co-morbidities and a higher peri-operative risk.\textsuperscript{1,10}

However, the using of posterior to anterior screw for posterior talar process fractures is still limited due to complex anatomical features of posterior talar process. The posterior screw may violate the posterior calcaneal articular surface, the tarsal canal, and the sinus tarsi.\textsuperscript{10,11} Therefore, posterior screws placement for posterior talar process should avoid to damage articular cartilage is essential for the success of the procedure.

To our knowledge, however, the relationship between the insertion angle of posterior screw placement for posterior talar process and safe zone has not been evaluated. The purpose of this study is to stress the importance of minimally invasive approach in displaced fracture of posterior talar process and to identify safe entry angulations. In addition, the cross-sectional areas of safe zone and average screw length for fixation from posterior screw position were measured using 3-dimensional (3D) reconstruction technique based on computed tomography (CT) images.
2. Materials and methods

2.1. Data collection

This study was conducted at the Affiliated Hospital of Medical School of Ningbo University in accordance with the Declaration of Helsinki (World Medical Association). Informed consent was obtained from the patients who participated in this study. This study was carried out according to the existing rules and permission of Ethics committee of the affiliated hospital of medical school of Ningbo University. One hundred Chinese patients were recruited between January 2015 and January 2017 in this study. There were 62 males and 38 females with an average age of 42 years (range, 25–62 years). We evaluated the CT image data of 100 patients who had visited for ankle and foot bone checkup. Patients who had pain of ankle and foot, but any evidence of talar fracture and osteoporosis were excluded. All CT scans were performed using a 256-slice Siemens CT scan (GE) with 1.0 mm slices at 0.1 s intervals for imaging of the talar. The raw data obtained were stored in DICOM (Digital Imaging and Communications in Medicine) format in a computer.

2.2. Model reconstruction

DICOM raw data sets were reconstructed into 3D models using the software Materiaise’s interactive medical image control system (MIMICS) 18.01 MIMICS, Leuven, Belgium). After obtaining 3D reconstructions of original CT scans, the simulation of inserting virtual computer-aided design (CAD) screw (diameter 3.0 mm) was performed, positioning the 2 screws into the medial and lateral tubercle of posterior talar process respectively. The achieved position of each screw was checked using the 3D reconstructions and 3 different 2D images, taken in 3 different planes (axial, coronal and sagittal), thus enabling assessment of potential perforation into the subtalar or the ankle joint.

2.3. Longest screw and path analysis

To determine the screw path in the 3D model from 1 single perspective, the transparency of 3D model was downgraded and turned to the axial perspective to find the largest translucent area by visual observation. Then 2 virtual CAD screws (3 mm in diameter) were placed medial and lateral tubercle of posterior talar process to the screen into the center of translucent area. The maximum screw length was measured between the 2 fixed points, using the entry point of each screw and the exit point on the far cortex. The high-risk zone with the smallest bolt-to-cortex distances was identified using 3 different 2D plane views. The maximum implant area was defined as the screw which did not penetrate the outline of translucent area. The overall diameter of identified high-risk zone and the distance from the entry point of the screw were both measured with the help of further set points. The shortest distance between each screw and the subtalar and ankle joint was separately evaluated. Three reference planes were used for the measurement of screw position angles: sagittal (defined by the midline of between medial and lateral malleolus), transverse (perpendicular to the sagittal plane) and coronal (perpendicular to the transverse plane). The 3D MIMICS software was used to measure the angles between the 2 CAD bolts and the respective reference planes (Figs. 2 and 3).

First, the position of 3D model was adjusted in the axial perspective to find the largest translucent area by visual observation. Then 2 virtual CAD screws (3 mm in diameter) were placed medial and lateral tubercle of posterior talar process to the screen into the center of translucent area. The maximum screw length was measured between the 2 fixed points, using the entry point of each screw and the exit point on the far cortex. The high-risk zone with the smallest bolt-to-cortex distances was identified using 3 different 2D plane views. The maximum implant area was defined as the screw which did not penetrate the outline of translucent area. The overall diameter of identified high-risk zone and the distance from the entry point of the screw were both measured with the help of further set points. The shortest distance between each screw and the subtalar and ankle joint was separately evaluated. Three reference planes were used for the measurement of screw position angles: sagittal (defined by the midline of between medial and lateral malleolus), transverse (perpendicular to the sagittal plane) and coronal (perpendicular to the transverse plane). The 3D MIMICS software was used to measure the angles between the 2 CAD bolts and the respective reference planes (Figs. 2 and 3).

All measurements were performed by 2 independent observers, both being trained and experienced users of the computer software used. To validate the reproducibility and accuracy of the measurement protocol, each observer performed 5 sets of...
measurements on each specimen. The variation between the measurements was ±2.5% for all the measured parameters. After establishing and verifying the measurement routine, further calculations of all the angles and distances were performed by the MIMICS software.

2.4. Definition of the safe zone

After the largest translucent area was determined, the Draw Freeform Curve function in mimics was used to draw the outline of between the medial and lateral tubercles in the 3D model (Fig. 4). The model was turned opaque when the drawing process was completed, and an irregular area surrounded by the curve was found in the talar body. The height of between the uppermost and downmost of placement screws was defined as the safe zone for lag screw fixation of posterior talar process (Fig. 5).

2.5. Statistical analysis

The results were exported into Excel file format. All statistical calculations were done using Microsoft Excel 2003 (Microsoft Headquarters, Redmond, WA). All experimental data (continuous variables) was presented as the mean and standard deviation or median and range. Statistical analysis was made using the Statistical Package for Social sciences (SPSS, IBM) version 20.0. The statistical significance level was defined as *P* < .05. The Kolmogorov-Smirnov test was used in the distribution of cases. For data showing a normal distribution, the groups were compared by gender using independent samples *t* test. The paired samples *t* test was used to compare the means for left side with right side.

3. Results

3.1. Basic measurement results for posterior talar process

As much as 100 human adult talar specimens were studied. For each specimen, range of the posterior talar process length width, height measurements were performed for the left and right region respectively, and the mean of these 2 measurements was calculated for further statistical analysis. The mean value, standard deviation, and range of morphometric measurements are shown in Table 1 according to gender. No statistical significance was found by gender or sides difference between these.

3.2. Safe zone of screw insertion

Each safe zone was above the entry point, which means screw should be inserted from posterior superior to anterior inferior in the talar body. The mean screw length from the medial tubercle entry point to distal cortex was 48.7 ± 1.2 mm. The angle between the medial tubercle screw and the sagittal plane was 16.4° ± 4.4°, whilst the mean angle between the screw and the transverse plane was 25.3° ± 3.5°. The mean screw length from the lateral tubercle entry point to distal cortex was 55.11 ± 1.2 mm. The angle between the lateral tubercle screw and the sagittal plane was 12.4° ± 3.4°, while the mean angle between the screw and the transverse plane was 17.3° ± 4.6°. Then the range of screw paths trajectories was modeled as the conical projection oriented from the entry point to the safe area of 1 coronal section. The width of this safe zone of lateral tubercle and medial screw were 15.3 ± 1.3 mm and 10.3 ± 2.3 mm, respectively.
Although the distances from the point of lateral tubercle were longer than those to the point of medial tubercle, the length of fixation 3.0mm-diameter screws was range from 55.11 ± 1.2 mm to 57 ± 1.4 mm. The minimum safe screw length was 45.6 mm among talar body. In addition, the distance between lateral tubercle and medial tubercle ranged from 16.2 to 19.3 mm, the mean distance was 18 ± 1.5 mm.

The lateral tubercle screw was longer in males, with a longer distance from the entry point to the narrowest zone. However, the narrowest zone of the lateral tubercle was smaller in women. The medial screw was longer in men along with the distance from the medial tubercle entry point to the narrowest zone. The narrowest zone of the medial tubercle bone was also smaller in females. These gender-specific measurements were all significant (P < .001). A paired samples t test was performed to compare the means of the left and right sides. No statistically significant difference was observed in the distance by gender and side.

4. Discussion

The posterior talar process fracture is an uncommon fracture, and it is easily undiagnosed by orthopedic surgeons. In literature search, there are few studies about this injury, but most of them are case reports. Furthermore, there is currently little information about anatomical dimensions of posterior talar process and potential anatomical variations. The precise location and dimension of hazardous zones, where a breach of neurovascular bundle and flexor hallucis longus tendon or perforation of the ankle and subtalar joint is a common danger, are also poorly understood. None of the available literature describes precisely the exact 3D position of the screw placement with regarding to safe screw angle and length.

The literature contains few reports on minimally invasive fixation of talar fractures using percutaneous screws. Most reports focused on surgical technique for talar neck fracture. Although several studies have reported using different approach for medial or lateral tubercle fracture of posterior talar process, none of the available literature described precisely the exact 3D position of screw placement with regarding to safe screw angles and lengths.

Total anterior and posterior patterns are extremely rare described. But the posterior process fracture represents a unique challenge for orthopaedic surgeon to access and reduce,

|    | Male       | Female     | P value |
|----|------------|------------|---------|
| Length, mm | 12.5 ± 3.14 | 11.02 ± 2.22 | .12     |
| Width, mm  | 19.5 ± 2.14 | 17.02 ± 1.22 | .17     |
| Height, mm | 10.5 ± 1.04 | 8.32 ± 2.04  | .19     |

The P values were determined using independent sample t test. Significance levels are one symbol: P < .05. mm = millimeter.)
especially when fracture was displaced or comminuted. Delee[16] found 2% incidence of subtalar dislocations in major dislocations. According to previous reports, an entire posterior process talar fracture is a rare injury.[11,17,18] Anatomically, the posterior process is composed of medial and lateral tubercles. A fracture of either tubercle is more common than fracture of the entire posterior process.[19]

When the fragments are displaced, it may cause repetitive irritation to the flexor hallucis longus tendon and simulate a clinical condition which was called pseudo hallux rigidus. The posterior process of the talus involves tibiotalar (posterior ankle) and talocalcaneal (posterior facet of the subtalar) joints. Minimal displacement of fracture fragment can result in substantial joint misalignment and posttraumatic arthritis, and for this reason accurate reduction and stable fixation are crucial and recommended. The technique involved placing 1 or 2 cannulated screws to stabilize the fracture with the open reduction internal fixation technique.[10,11] One theoretical limitation of placing a posterior percutaneous screw is risk to local anatomic structures because of the neurovascular bundle and the FHL running deeper adjacent to the posterior talar process.[20]

To authors’ knowledge, there are no reports on minimally invasive fixation of posterior talar process fractures using percutaneous screws. A case of the same technique was described in our previous study.[10] We have operated on 1 patient with a small incision and overall satisfying clinical results. But we did not describe any measurement and parameter of posterior talar process, also did not comment on the accuracy position of screw placement. This may be the main limitation when other orthopedic surgeon using posterior screw insertion in posterior talar process fractures. Recognizing the influence of anatomic region on accuracy of assessing screw position may help surgeon avoid placing screws that penetrate the subtalar and ankle joint or injuring the neurovascular bundle and tendon.

This study identified a safe zone for posterior screw insertion. Each safe zone was above the entry point, which means screws should be inserted from posterior superior to anterior inferior in the talar body. The different safe entry distance among all talus was 48.7±1.2 mm and 55.11±1.2 mm. Based on these results, we believe that inserting one 48.7 mm screw and 55 mm from the medial and lateral tubercle of the posterior process of the talus towards the talar head is safest, respectively. But this 2 different entry point screws have different safe zone for fixation. The width of this safe zone of the lateral tubercle and medial screw was 15.3±1.3 mm and 10.3±2.3 mm, respectively. The difference between medial tubercule and lateral tubercule was similar with the width of 2 parallel placed screws (the distance between 2 centers of screws was more than 2 mm), which indicated that placing 2 vertical parallel screws was of high risk, while horizontal parallel insertion would be safer.

In this study, we described measurements of the safe zone and the longest screw from entry points to bone cortical. We evaluated these zones along the 3 virtual CAD screws, hence these measurements objectively show the anatomical bottle necks which are found during surgery. Knowing the exact location and diameter of these areas might reduce the risk of joint penetration and neurovascular bundle damage.

The methodological improvement in this study made a larger screw diameter be possible, suggesting that the direction of screw insertion and entry point of the virtual screw could influence the maximum safe zone. Moreover, the method used in this study can identify a zone instead of screw insertion position.

The zone found in this study is the entry zone when the screw was placed in the largest intraosseous path of posterior talar process. It means that when a lag screw was inserted in medial and lateral tubercle, the lag screw placement angle can be evaluated pre-operation. Screw penetration into the joint will be avoided, as more fluoroscopy usage and operative time will be reduced from the screw to an acceptable position. In some situations, the length of insertion screw can be achieved pre-operation, avoiding to place shorter screws with compromised stability or joint penetration and neurovascular bundle damage. The zone found in this study provides a larger operating space and insertion position, making insertion of long lag screw into the posterior talar process will be safer and easier.

The maximum area of medial and lateral tubercle in all the 50 models in this study were calculated larger than 36.0 mm², which confirms the feasibility of successful application of one 4.0 mm or 4.5 mm lag screw in the fixation of the posterior talar process fractures by 2 different insertion points. Therefore, we suggest that the posterior talar process can provide osseous space large enough for insertion of a conventional diameter screw and give the surgeon more space for maneuver.

We have also confirmed other reports which are the feasibility to from the lateral tubercle posterior talar process towards the talar head is safest.[15]

As the range and standard deviation of our results are relatively large, it is recommended that individual preoperative plan should be implemented for each patient.

The safe zone and screw insertion direction are useful intra-operatively; it could significantly increase both the safety and feasibility of lag screw placement from posterior to anterior talus.

In this study the virtual screws were often extremely close to the subtalar joint. The percutaneous screws are impossible inserted by using a 2D fluoroscope in majority of clinical case. The more widespread use of 3D fluoroscope and computer-navigated surgery might reduce the risk of joint penetration and neurovascular bundle damage with preoperative planning and during the procedure.

Besides the safe zone, the screw direction is another important factor affecting the safe placement of a long lag screw. This study showed that the angle of screw between male and female were significantly different. This may be due to anatomic differences in talar bones between female and male. Therefore when a lag screw was inserted into a male posterior talar process, the angle between the guide pin and sagittal plane should be appropriately reduced. Knowledge of the different angles according to the gender of the patient could be useful during the procedure. Even with experienced surgeons, it is still difficult to insert the lag screw along the desired direction intra-operatively. This might be helpful in determination of entry point and orientation of the screw, facilitating intra-operative screw insertion.

### 5. Limitations

There are several limitations to this study. First, there is lack of consideration of the horizontal direction of safe zone and lack of combined cadaveric body experiments. Second, the accuracy of the safe zone has not been verified from the clinical aspect. More related clinical research should be performed. Finally, while this study offers guideline for a safe zone of screw placement for posterior talar process, this is based on normal talus without any fracture using a 99% confidence interval of screw penetration. Future study would be needed to do more cadaveric and clinical study validate these guidelines.
6. Conclusion

In summary, the study provides enough information for the posterior minimal invasive technique to posterior talar process fracture with characterization of safe zones, which might contribute to accuracy of this highly demanding technique. Additionally, minimize the intraoperative risk of lesion of neurovascular structures is necessary by a screw, recommending a preoperative individual preoperative planning to allows better virtual screw placement. It delineates 2 insertion points in the posterior talar process available for screw path and defines a safe zone for lag screw insertion. With careful preoperative planning, screw placement can be safely done within the safe zone as defined by our method.

Author contributions

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References

[1] Letonoff EJ, Najarian CB, Suleiman J. The posteromedial process fracture of the talus: a case report. J Foot Ankle Surg 2002;41:52–6.
[2] Nadim Y, Tossic A, Ebraheim N. Open reduction and internal fixation of fracture of the posterior process of the talus: a case report and review of the literature. Foot Ankle Int 1999;20:50–2.
[3] Chen YJ, Hsu RW, Shih HN, et al. Fracture of the entire posterior process of talus associated with subtalar dislocation: a case report. Foot Ankle Int 1996;17:226–9.
[4] Mao H, Shi Z, Liu Z, et al. Minimally invasive technique for medial subtalar dislocation associated with navicular and entire posterior talar process fracture: a case report. Injury 2015;46:759–62.
[5] Liu Z, Zhao Q, Zhang L. Medial subtalar dislocation associated with fracture of the posterior process of the talus. Journal of pediatric orthopedics Part B 2012;21:439–42.
[6] Naranja RR Jr, Monaghan BA, Okereke E, et al. Open medial subtalar dislocation associated with fracture of the posterior process of the talus. J Orthop Trauma 1996;10:142–4.
[7] Chen YJ, Hsu RW. Fracture of the posterior process of the talus associated with subtalar dislocation: report of a case. J Formosan Med Assoc Taiwan yi zhe 1994;93:802–5.
[8] Ebraheim NA, Snie MC, Podeszwa DA. Medial subtalar dislocation associated with fracture of the posterior process of the talus. A case report. Clin Orthop Relat Res 1994;303:226–30.
[9] Shi Z, Zou J, Yi X. Posteromedial approach in treatment of talar posterior process fractures. J Invest Surg 2013;26:204–9.
[10] Ebraheim NA, Mekhal AO, Salpietro BJ, et al. Talar neck fractures: anatomic considerations for posterior screw application. Foot Ankle Int 1996;17:541–7.
[11] Lemaire RG, Bustin W. Screw fixation of fractures of the neck of the talus using a posterior approach. J Trauma 1980;20:669–73.
[12] Abdelgaid SM, Ezzat FF. Percutaneous reduction and screw fixation of fracture neck talus. Foot Ankle Surg 2012;18:219–28.
[13] Fernandez ML, Wade AM, Dabbah M, et al. Talar neck fractures treated with closed reduction and percutaneous screw fixation: a case series. Am J Orthop 2011;40:72–7.
[14] Amoretti N, Huwart L. Percutaneous screw fixation of a talar fracture under computed tomography and fluoroscopy guidance. J Vasc Interv Radiol 2012;23:1711–2.
[15] Wu JQ, Ma SH, Liu S, et al. Safe zone of posterior screw insertion for talar neck fractures on 3-dimensional reconstruction model. Orthop Surg 2017;9:23–33.
[16] DeLee JC, Curtis R. Subtalar dislocation of the foot. J Bone Jt Surg Am Vol 1982;64:433–7.
[17] Mehrpour SR, Aghamirsalim MR, Sheshvan MK, et al. Entire posterior process talus fracture: a report of two cases. J Foot Ankle Surg 2012;51:326–9.
[18] Bhanot A, Kaushal R, Bhan R, et al. Fracture of the posterior process of talus. Injury 2004;35:1341–4.
[19] Kavravos SJ, Schoenhaus HD, Jay RM. Fracture of the posterior process of the talus. Case Rep J Am Podiatry Assoc 1983;73:421–2.
[20] Beltran MJ, Mitchell PM, Collinge CA. Posterior to anteriorly directed screws for management of talar neck fractures. Foot Ankle Int 2016;37:1130–6.