Preoperative Computed Tomography in Guiding the Length of Cannulated Screws in Medial Malleolar Fractures

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Research article

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Abstract

Introduction: Excessive lengths of partially threaded cannulated screws in medial malleolus fractures are often related to failure of fixation and other complications. This study aimed to analyze the distribution and density of cancellous bone in the medial malleolus among healthy individuals and provide a theoretical basis for determining the lengths of cannulated screws based on preoperative computed tomography (CT) to achieve stable fixation of medial malleolus fractures.

Methods: Between January 2012 and December 2016, 100 patients (without ankle fractures) who underwent CT of the distal tibia of the lower extremities were included. Specific levels on the CT images were selected to assess the density and length of valid cancellous bone in the medial malleolus for screw fixation. Meanwhile, we followed up 44 patients who underwent open reduction and internal fixation (ORIF) of medial malleolus fractures based on preoperative CT-based measurements.

Results: The valid lengths of cancellous bone in the medial malleolus were significantly different between men and women ($p < .05$). In addition, there was a significant difference among different age groups ($p < .05$). The median follow-up duration of patients who underwent ORIF was 14 (range, 12–16) months. All patients were followed up to union without displacement, and no screws were observed to have loosened or backed out.

Conclusion: Preoperative CT can help determine the length and location of cannulated screws. Age and gender have a considerable impact on the distribution and density of cancellous bone in the medial malleolus. The density and length of valid cancellous bone decrease with age. The shoulder of the tibial plafond in medial malleolus, which is a weak part of cancellous bone, is a common site of fracture. Short screws are recommended for fixation in elderly patients.

Level of Evidence: Level IV

Introduction

Ankle injuries are one of the most common acute injuries in the emergency room, including ankle ligament avulsions and ankle fractures.[1] Medial malleolar fractures make up a large proportion of these fractures, which may occur both in isolation and in conjunction with fractures of the lateral and posterior malleolus.[2–4] There are many types of operative internal fixations for medial malleolus fractures including, fully threaded (FT) cannulated screw, partially threaded (PT) cannulated screw, sled fixation and Kirschner wire tension band fixation.[5,6 7–9 10]At present, the most commonly accepted method is to use 1 to 2 PT cannulated screw(s) to fix the ankle in a parallel manner according to the size of the fracture block.[6,7]

To purchase enough pullout strength within the distal tibial metaphysis, the PT cannulated screws must be long enough for the threads to pass beyond fracture line, since the holding force of the screws is mainly concentrated on the thread at the tail end However, an excessively long PT cannulated screw will cause the threads to fall into the medullary cavity, thereby losing its pullout strength.[11] In addition, soft-tissue irritation secondary to loosened and backed out PT cancellous screws may occur, which causes persistent pain after fixation.[12,13] Some studies have demonstrated that ankle pain is one of the main complications after fixation of the medial malleolus using PT cannulated screws.[14–17] Therefore, appropriate screw lengths for medial malleolar fixation can possibly reduce the failure of internal fixation and minimize complaints of prominent hardware. Previous studies have shown that computed tomography (CT) attenuation in Hounsfield Unit (HU) are positively correlated with bone mineral density (BMD).[18,19] Since BMD is closely related to bone density, the distribution and density of cancellous bone in the medial malleolus can be evaluated by measuring HU value. However, no previous study has focused on this topic. This study was designed to assess an appropriate method to guide the lengths of cannulated screws for the fixation of the medial malleolus based on the measurement of HU values of the distal tibia.

Materials And Methods

Patients

The study protocol was approved by the ethics committee of our hospital. Between January 2012 and December 2016, 100 patients of different ages in our department who underwent CT of the distal tibia without lower limb fractures were included, of whom 54 were male and 46 were female. The exclusion criteria included patients aged younger than 18 years, with a history of fractures, with arthritis, and with a history of chronic diseases that may cause osteoporosis. They were divided into 3 groups according to age: group A (median age, 30.3 years; range, 18–40), including 16 men and 14 women; group B (median age, 52.0 years; range, 41–60), including 23 men and 15 women; and group C (median age, 74.8 years; range, 61–87), including 15 men and 17 women.

Methods of Observation of Cancellous Bone

Sixteen-slice spiral CT of the bilateral lower-extremity tibia was performed in 100 cases, with a 1-mm thin-layer scan ranging from the tibial tubercle to the calcaneus. The data were exported using a DICOM image format after being processed by the CE workstation (Centricity Radiology RA 600 V8.0) and imported to MIMICS, and the image was adjusted to a bone window with a width of 1500 Hounsfield units (HU) and window position of 350 HU.

The amount of data of the CT scan was large. Therefore, it was not feasible to perform a complete evaluation of cancellous bone in the medial malleolus. A simple and efficient method was to choose a relatively fixed level for evaluation. For medial malleolus fractures, the most common method of fixation was to use 1 to 2 PT cannulated screw(s) based on the size of the fracture block.[6,7] The positions of the screws were located in the anterior third, half, and posterior third of the medial malleolus in the sagittal plane. Therefore, we divided the medial malleolus into the anterior third, half, and posterior third at the level of the tibial plafond, and the CT images of the three sections were reconstructed on the coronal plane (Fig. 1).

To observe the density of cancellous bone in the medial malleolus, the standard HU value of cancellous bone needed to be defined. The commonly accepted density based on cancellous bone’s HU value is 130 ± 100 HU, and the HU value of the cortex is considered to be greater than 400 HU, which is controversial and does not exhibit continuity. In fact, we found that there is no clear cutoff HU value among different tissues. Often, there is a certain intersection range between them, that is, the transition interval. To observe the distribution of the cancellous bone and to guide the lengths of cannulated screws for the fixation of the medial malleolus, the interval of the HU value of cancellous bone must be identified.

The purpose of setting an upper limit of the HU value of cancellous bone is to improve the specificity of cancellous bone in the color-coded area. High-density cancellous bone should be included while cortical bone should be excluded. We marked yellow for HU values higher than 230 HU; 315 HU, which is the median of the upper limit of cancellous bone (230 HU) and lower limit of cortical bone (400 HU); and 400 HU. An ideal cutoff value should be set when all cancellous bones are not labeled exactly while the cortex is continuous.

The purpose of selecting a lower limit of HU values of cancellous bone is to remove the interference from other tissues and improve the specificity of distinguishing cancellous bone. We marked green for CT values higher than 30 HU, which is the commonly recognized lower limit of cancellous bone; 130 HU (mode); and 400 HU. An ideal cutoff value should be set when all cancellous bones are not labeled exactly with the surrounding fatty tissue, muscle, and other soft tissues visible.

Evaluation of the Density of Cancellous Bone in the Medial Malleolus

Since the average HU value of cancellous bone, which is 130 HU, is considered to correspond to valid bone tissue, which can provide a good holding force for the PT screws. Tissues with HU values between 230 HU and 400 HU were defined as high-density bone tissues. We marked the areas with HU values between 130 HU and 230 HU as blue, greater than 230 HU and less than 400 HU as green, and greater than 400 HU as yellow. In this mask range, high-density cancellous bone was clearly displayed with the surrounding soft tissue excluded. We measured the distances from the medial malleolus colliculi to valid cancellous bone and the contralateral cortices, which were both parallel to the medial malleolus cortical bone, calculated their ratios, and analyzed the data.

Clinical Follow-up

Forty-four patients with medial malleolus fractures between January 2014 and December 2016, including 24 men and 20 women (median age, 46 years; range, 20–83), were followed up. There was an average of 2 days from admission to operation (range 4 hours-5 days). Preoperative CT was performed in patients with medial malleolar fractures to guide the length of the PT cannulated screws (Fig. 2). All patients underwent open reduction and internal fixation by two orthopedists in our department. The implants were titanium PT cannulated screws (General Electric Company, USA) with a diameter of 3.5 to 4.5 mm and length of 30 to 45 mm. The screws were PT with cannulated screws as required. We ensured anatomical reduction of the fracture using intraoperative fluoroscopy. Postoperative antibiotics were standardly administered for 2 to 3 days to prevent infection. Functional exercises of the ankle could be performed in bed the next day after the anesthesia effects wore off and moderately increased in the subsequent days. Weightbearing on the injured side was allowed gradually after 6 to 8 weeks. Gradually, walking and daily activities were resumed when X-ray examinations showed clinical recovery of the fracture. We followed up these patients to observe complications and the impact of the length of the PT cannulated screws on medial malleolus fracture fixation.

Statistical Analysis

All statistical analyses were performed using IBM SPSS version 16.0 software (IBM Corp, Armonk, NY). Means were compared between different age and gender groups. The Student's *t* test was used for the group comparison analysis performed of data conforming to a normal distribution. The probability of the null of $p < .05$ was considered statistically significant.

Results

Observation Methods of Cancellous Bone

For the upper limit of the HU value of cancellous bone, most of the cancellous bone remained visible when it was marked yellow in the areas with values greater than 230 HU or 315 HU using labeling tools in MIMICS. However, when the cutoff value was set to 400 HU, the cancellous bone was not labeled exactly while the cortex was displayed correctly and continuously.

For the lower limit of the HU value of cancellous bone, cancellous bone in the medial malleolus was correctly displayed with the surrounding skin, muscle, and other soft tissue remaining visible when we set a label mask to 30 HU (green area). However, when the cutoff value was set to 130 HU, cancellous bone in the medial malleolus was correctly displayed and labeled green. Soft tissues such as the skin and muscles were not labeled.

In order to reduce the interference of soft tissues such as fat, blood vessels, and bone marrow in cancellous bone, we set the average HU value of cancellous bone, 130 HU, as a cutoff value. HU values greater than 130 HU but less than 230 HU were low-density valid cancellous bone, which were marked blue. Those greater than 230 HU but less than 400 HU were high-density valid bone, marked green. Meanwhile, those greater than 400 HU were marked yellow (Fig. 3).

Evaluation of the Density of Cancellous Bone in the Medial Malleolus

It was found that cancellous bone in the medial malleolus of patients in our study was concentrated within the distal tibial metaphysis. However, the density at the shoulder of the tibial plafond, a common site for fractures, decreased notably.

Using MIMICS 16.0, we measured the distances from the medial malleolus colliculi to valid cancellous bone and contralateral cortices, both parallel to the medial malleolus cortical bone in different gender and age groups.

Statistics of the Anterior Third Medial Malleolus

The average length of valid cancellous bone in the anterior third medial malleolus in our study was 41.24 mm, and the length ratio was 53.42%. In group A, the length of valid cancellous bone was 46.84 ± 6.29 mm and length ratio was 63.27% ± 8.11% in men, while the length of valid cancellous bone was 44.25 ± 3.52 mm and length ratio was 59.91% ± 5.06% in women. In group B, the length of valid cancellous bone was 41.07 ± 4.31 mm and length ratio was 56.05% ± 5.79% in men, while the length of valid cancellous bone was 37.67 ± 4.00 mm and length ratio was 49.55% ± 5.30% in women. In group C, the length of valid cancellous bone was

34.67 ± 2.68 mm and length ratio was 47.90% ± 3.52% in men, while the length of valid cancellous bone was 31.82 ± 4.65 mm and length ratio was 43.53% ± 6.63% in women.

Statistics of 1/2 of the Medial Malleolus

The average length of valid cancellous bone in 1/2 of the medial malleolus in our study was 39.53 mm, and the length ratio was 53.50%. In group A, the length of valid cancellous bone was 46.91 ± 6.87 mm and length ratio was 63.28% ± 8.04% in men, while the length of valid cancellous bone was 45.07 ± 3.04 mm and length ratio was 60.45% ± 4.79% in women. In group B, the length of valid cancellous bone was 41.26 ± 4.19 mm and length ratio was 56.25% ± 5.68% in men, while the length of valid cancellous bone was 37.63 ± 3.89 mm and length ratio was 49.66% ± 5.38% in women. In group C, the length of valid cancellous bone was 34.30 ± 2.26 mm and length ratio was 47.38% ± 2.70% in men, while the length of valid cancellous bone was 31.94 ± 4.28 mm and length ratio was 43.63% ± 6.31% in women.

Statistics of the Posterior Third of the Medial Malleolus

The average length of valid cancellous bone in the posterior third of the medial malleolus in our study was 40.21 mm, and the length ratio was 55.28%. In group A, the length of valid cancellous bone was 49.00 ± 7.75 mm and length ratio was 68.03% ± 10.36% in men, while the length of valid cancellous bone was 45.21 ± 3.76 mm and length ratio was 61.77% ± 5.27% in women. In group B, the length of valid cancellous bone was 41.26 ± 4.19 mm and length ratio was 58.13% ± 6.34% in men, while the length of valid cancellous bone was 38.13 ± 4.45 mm and length ratio was 50.29% ± 5.98% in women. In group C, the length of valid cancellous bone was 35.10 ± 3.31 mm and length ratio was 49.31% ± 4.03% in men, while the length of valid cancellous bone was 31.97 ± 4.90 mm and length ratio was 43.73%±6.92% in women.

Assessing the Impact of Screw Length on Medial Malleolus Fractures

Forty-four patients were followed up for an average of 14 (range, 12–16) months, with 11 isolated medial malleolus fractures (OTA 43B), 20 bimalleolar fractures (OTA 44B) and 13 associated syndesmosis injuries (OTA 44C). The distribution of the causes of injury was 18 cases of sprains, 8 of fall injuries, 6 of impact injuries, and 12 of traffic injuries. All cases involved closed fractures with 25 cases involving the right ankle and 19 cases involving the left ankle. Reduction and internal fixation were favorable. All fractures healed without displacement or screw breakage and healed well after the operation. All patients achieved favorable functional restoration. The American Orthopedic Foot and Ankle Society score(AOFAS) was determined, indicating 30 cases assessed as excellent, 14 cases assessed as good, and no cases reported as poor. The percentage of positive rates was 100% (Fig. 4) (Table 1).

Table 1

Evaluation of cancellous bone density of medial malleolus

		Front 1/3		1/2 part of the medial malleolus		posterior 1/3	
		Valid length（mm）	Length ratio（%）	Valid length（mm）	Length ratio（%）	Valid length（mm）	Length ratio（%）
Group A	Male	46.84 ± 6.29	63.27±8.11	46.91±6.87	63.28±8.04	49.00±7.75	68.03±10.36
	Female	44.25±3.52	59.91±5.06	45.07±3.04	60.45±4.79	45.21±3.76	61.77±5.27
Group B	Male	41.07 ± 4.31	56.05±5.79	41.26±4.19	56.25±5.68	41.26±4.19	58.13±6.34
	Female	37.67 ± 4.00	49.55±5.30	37.63±3.89	49.66±5.38	38.13±4.45	50.29±5.98
Group C	Male	34.67 ± 2.68	47.90±3.52	34.30±2.26	47.38±2.70	35.10±3.31	49.31±4.03
	Female	31.82 ± 4.65	43.53±6.63	31.94±4.28	43.63±6.31	31.97±4.90	43.73±6.92

Discussion

The stability of fractures is key to successful treatment, enabling patients to perform early functional exercises to obtain better treatment results and reduce the incidence of traumatic arthritis.[2] PT cannulated screws are broadly used to fix the ankle according to the size of the fracture block, although complications such as ankle pain secondary to loosened and backed-out screws occur in about 20% of patients, which may be largely related to the excessive lengths of PT cannulated screws. Preoperative CT can help clinicians determine the length and location of PT cannulated screws. As a commonly used clinical examination, CT cannot comprehensively show the density of cancellous bone in the distal end of the tibia. Simplifying the methods of measurement and improving its efficiency are crucial. More importantly, standardized methods of measurements increase the repeatability and reliability of these data, thus making it easy for clinicians to collect and compare parameters. However, to the best of our knowledge, there are still not enough related studies, and no clear quantitative indicators have been reported. Therefore, we analyzed specific levels of the medial malleolus on the coronal plane of CT images, which makes measurement simple, reliable, and repeatable.

Osteoporosis is an important factor affecting the internal fixation of fractures. It is correlated with an increased bone stiffness, deterioration of trabecular architecture, decreased bone mass and strength.[20,21] Experts have already been paying attention to this factor. Some studies have demonstrated that information about bone quality can also be evaluated via HU measurements obtained from CT scans,[16,22] while HU values of bones are positively correlated to their BMD.[18,19] The results of this study indicate that HU values of the medial malleolus are clearly correlated with age. The area of the HU value greater than 130 HU in patients older than 60 years of age is notably lower than that in the other two groups of patients, indicating that the length of valid cancellous bone in the medial malleolus in this group is remarkably shorter. As a result, screws of excessive length would gain poor purchase in the sparse cancellous bone and could not obtain stable internal fixation. Therefore, age is a factor that clinicians should consider when performing internal fixation. When a patient is older than 60 years, a possibly shorter screw is recommended after ensuring that the thread has passed through the fracture line. A 35-mm screw would have stronger holding power and stability. L.parker et al[11] in a cadaver study noted that shorter screws are recommended in osteoporotic bone so as to improve the purchase of the screw threads and compression at the fracture site. They also demonstrated that either a 45-mm fully threaded screw or a 30-mm partially threaded screw but not with a 45-mm partially threaded screw was more likely to purchase enough in the physeal scar, which we defined as valid cancellous bone.

Multiple studies have mentioned alternative strategies in fixing the medial malleolar fracture. [23–25] Christy M. King et al [26] and Jason D. Pollard et al [27] believed that fully threaded bicortical screw is an additional and acceptable treatment, especially in higher risk patient populations with poor bone stock and the 3.5 mm bicortical screws has greater pullout strength when compared with 4.0 mm partially threaded cancellous screws. Medial malleolar sled construct is also a good choice in fixation of horizontal medial malleolar fractures.[10] However, partially threaded cancellous screws still provide many advantages such as lower expenses, easier and quicker placement. According to the AO/ASIF technique, partially threaded cancellous screws is recommended for fixation of medial malleolar fracture. Henrik C. Bäcker et al's retrospective study indicated that unicortical screws fixation of the medial malleolar can achieve favorable clinical outcome with a low complication rate.[28]

The results of our study show that the length and ratio of valid cancellous bone in the posterior third of the medial malleolus is slightly larger than that in the anterior third and half of the medial malleolus. However, Femino et al.[29] argued that the posterior colliculus is not a safe zone to implant lag screws because they may raise the possibility of irritating the tibialis posterior tendon. The anterior colliculus is the safe zone to place lag screws.

This study has the following drawbacks including the inherent nature of a retrospective review. Second, the number of cases for clinical follow-up was small in our study. A large-scale cohort study can better reveal the effectiveness and complications of this fixation method. Additionally, there was no comparison group. Third, although some studies have shown that HU values of bones are positively correlated to their BMD,[18,19] most of them involved evaluations of HU values of the cervical spine and femur. No studies have analyzed the relationship between the HU value of the distal tibia and BMD. This may be a focus in future studies.

Conclusion

Preoperative CT can help determine the length and location of cannulated screws. Age and gender have considerable impacts on the distribution and density of cancellous bone in the medial malleolus. The density and length of valid cancellous bone decrease with age. The shoulder of the tibial plafond in medial malleolus, which is the weak part of cancellous bone, is a common site of fracture. Short screws are recommended for fixation when treating elderly patients.

Abbreviations

CT: computed tomography

ORIF: open reduction and internal fixation

FT: fully threaded

PT: partially threaded

HU: Hounsfield Unit

BMD: bone mineral density

AOFAS: American Orthopedic Foot and Ankle Society score

Declarations

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Authors' contributions

PCL, ZXC carried out the data analysis and drafted the manuscript. FY, JT, JL and XQW participated in the study design and discussion of the clinical results. CZ and JXX collected data. All of the authors read and approved the final manuscript.

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Ethics approval and consent to participate

The study was approved by Ethics Committee of the Shanghai Ninth People's Hospital, Shanghai JiaoTong University School of Medicine. Written informed consent was available, and participant involved gave his consent for the use of individual data and experimental data.

Availability of data and materials

The data used and analyzed during the current study is available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

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Figures

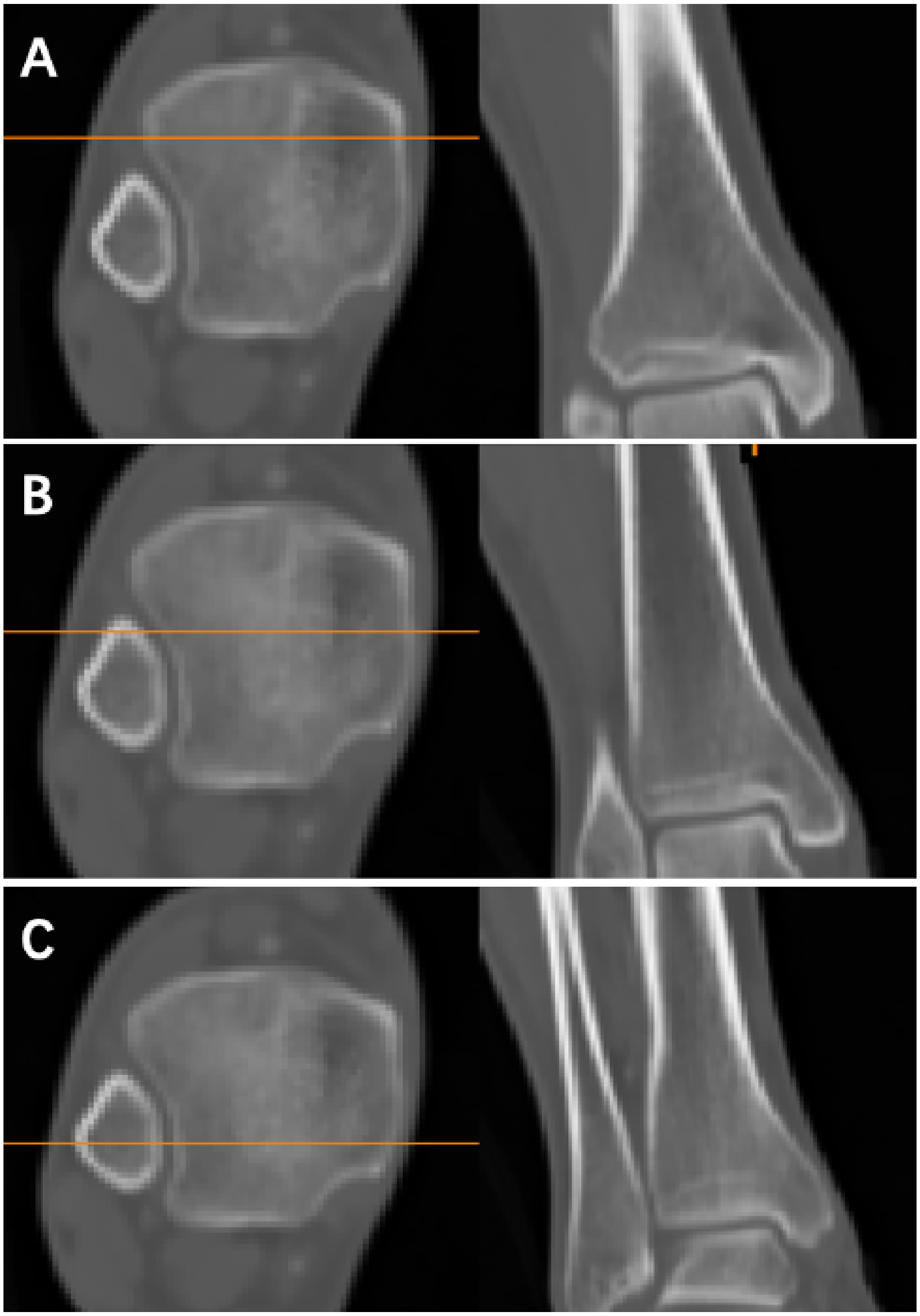
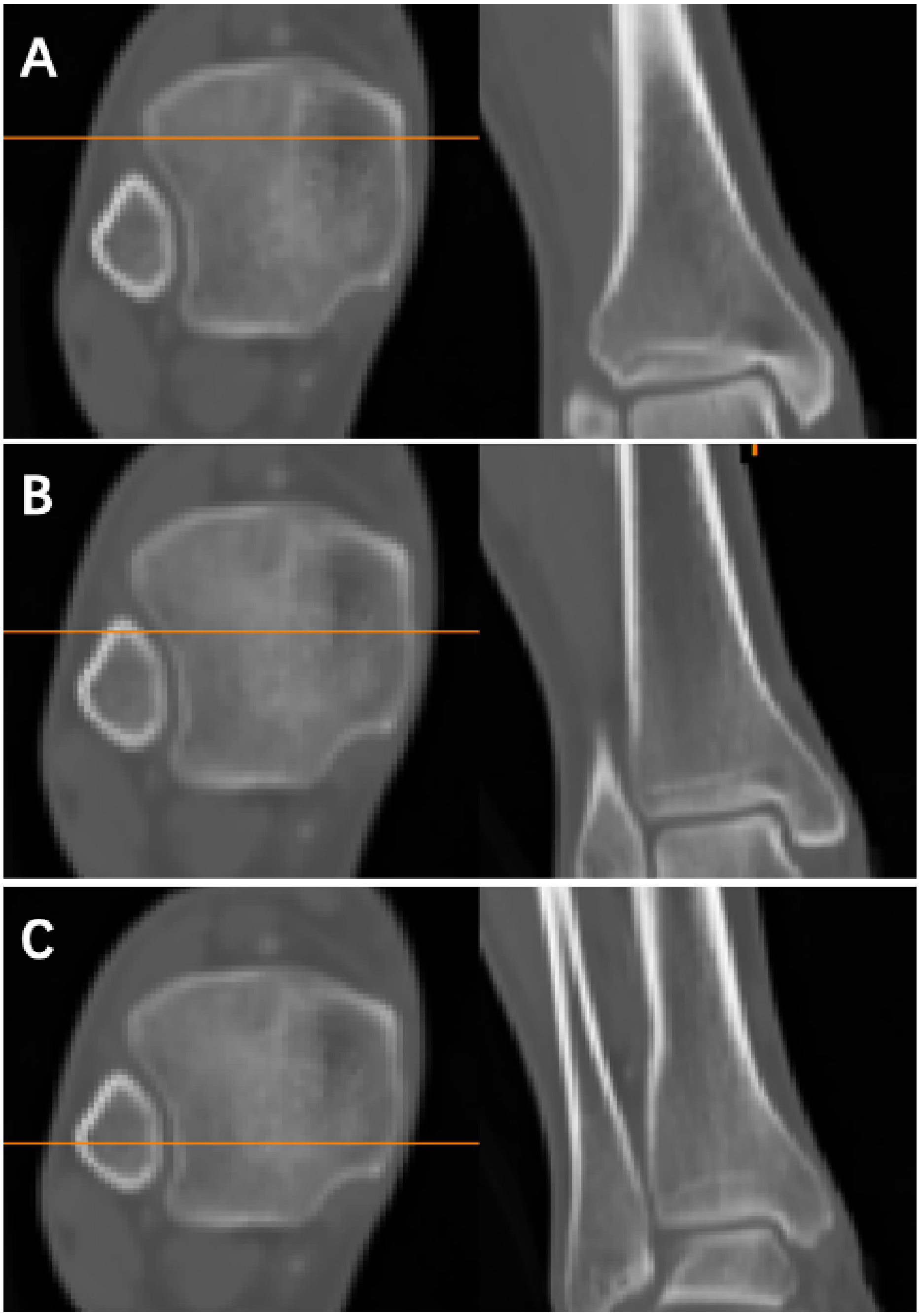


Figure 1

The medial malleolus was divided into anterior 1/3(A), 1/2(B), and posterior 1/3(C) at the level of tibial plafond and the CT images of three sections are reconstructed on the coronal plane.



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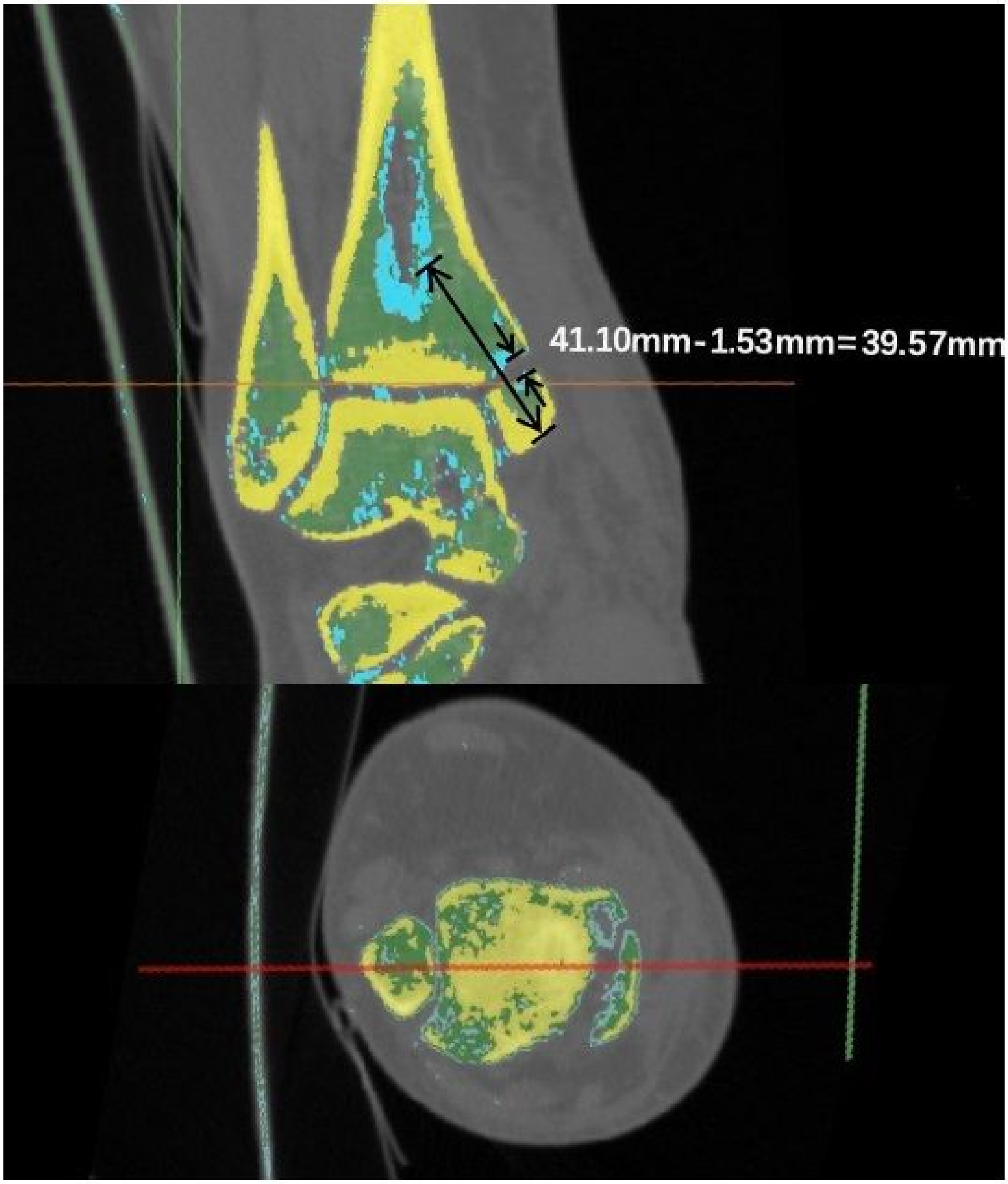
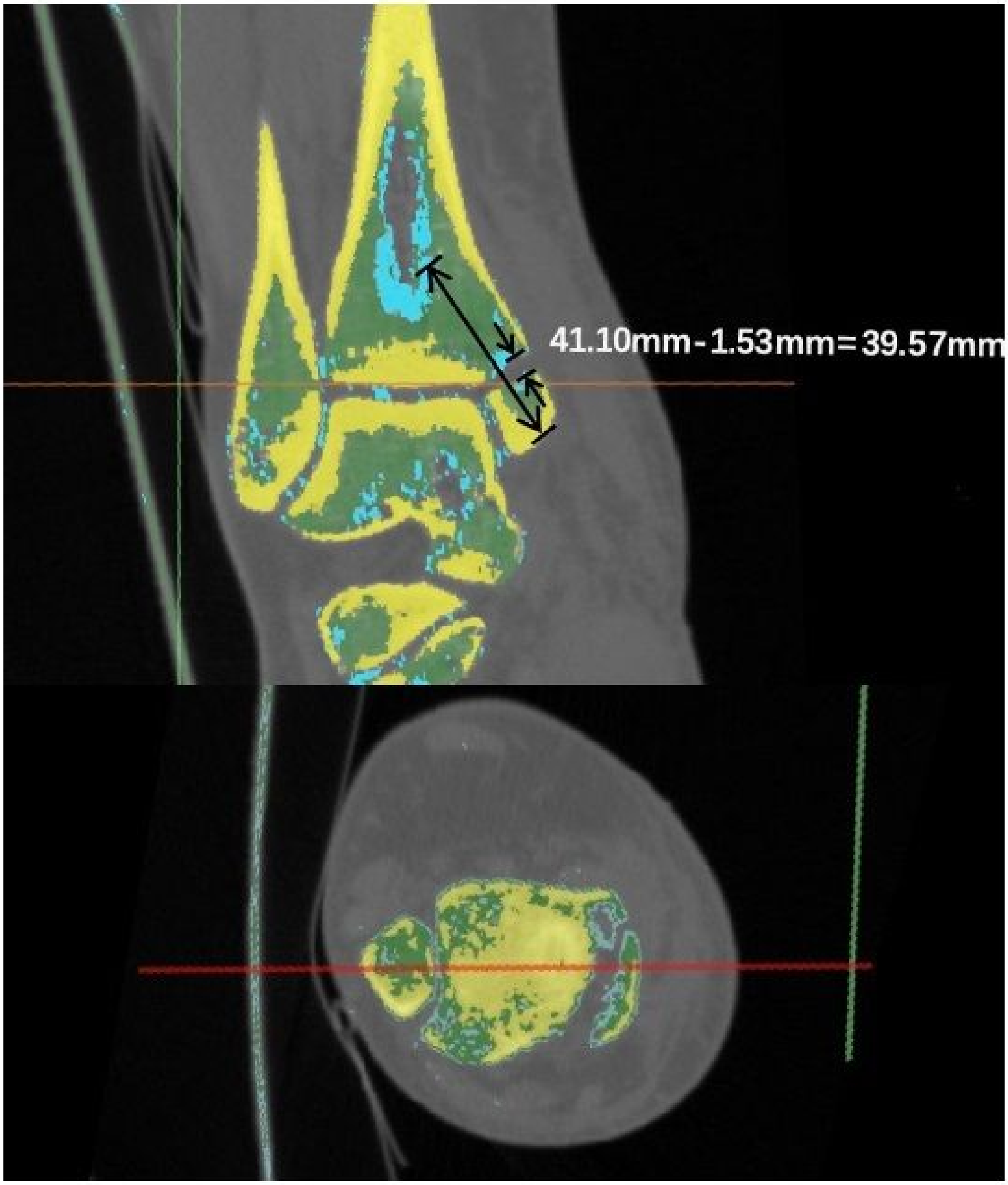


Figure 2

Preoperative CT scans were performed on the patients with medial malleolar fractures in order to guide the length of PT cannulated screws



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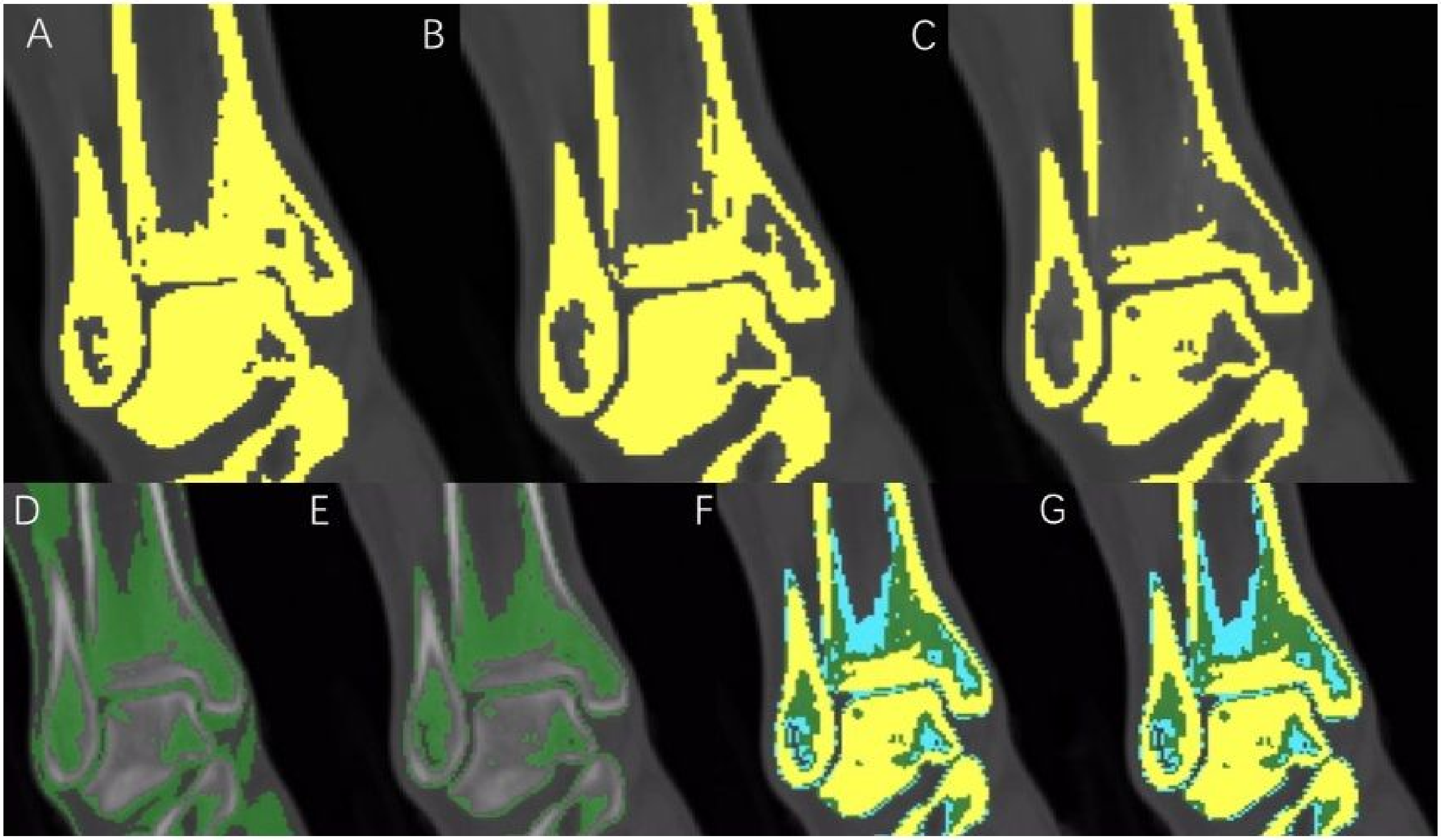
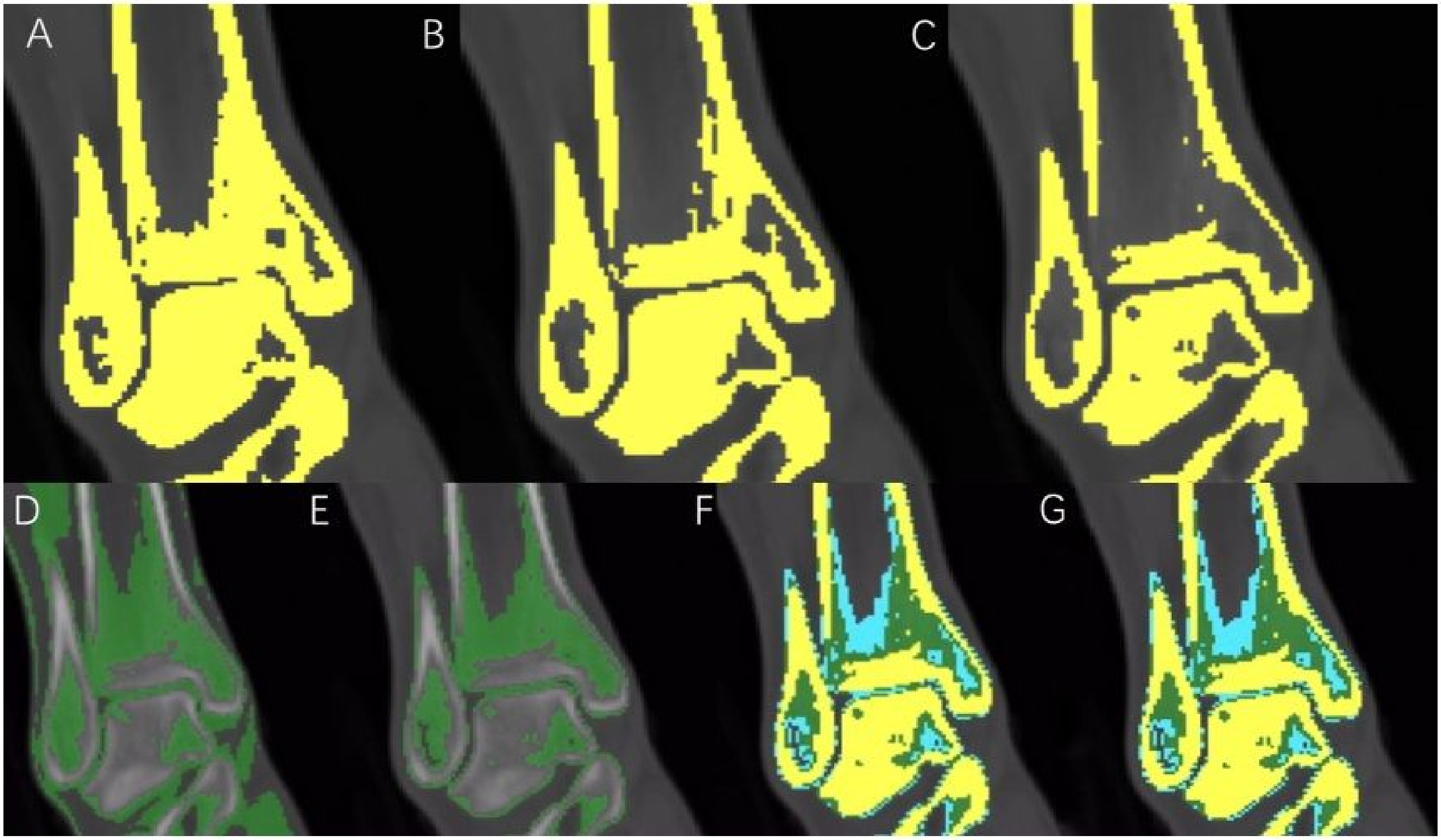


Figure 3

Most of the cancellous bone was still visible when we marked yellow to the areas above 230HU(A)or 315HU(B). However, when the cut-off value was set to 400HU(C), Cancellous bone was basically not labeled while the cortex was displayed correctly and continuously. The cancellous bone correctly displayed with the surrounding soft tissue still visible when the mask was set to 30HU(D). However, when the cut-off value was set to 130HU(E), cancellous bone in the medial malleolus was correctly displayed and labeled as green. Soft tissues such as skin, muscles were not labeled. The conjunction of the medial malleolus, which is the weak part of the cancellous bone, is the common site of fracture. (G)



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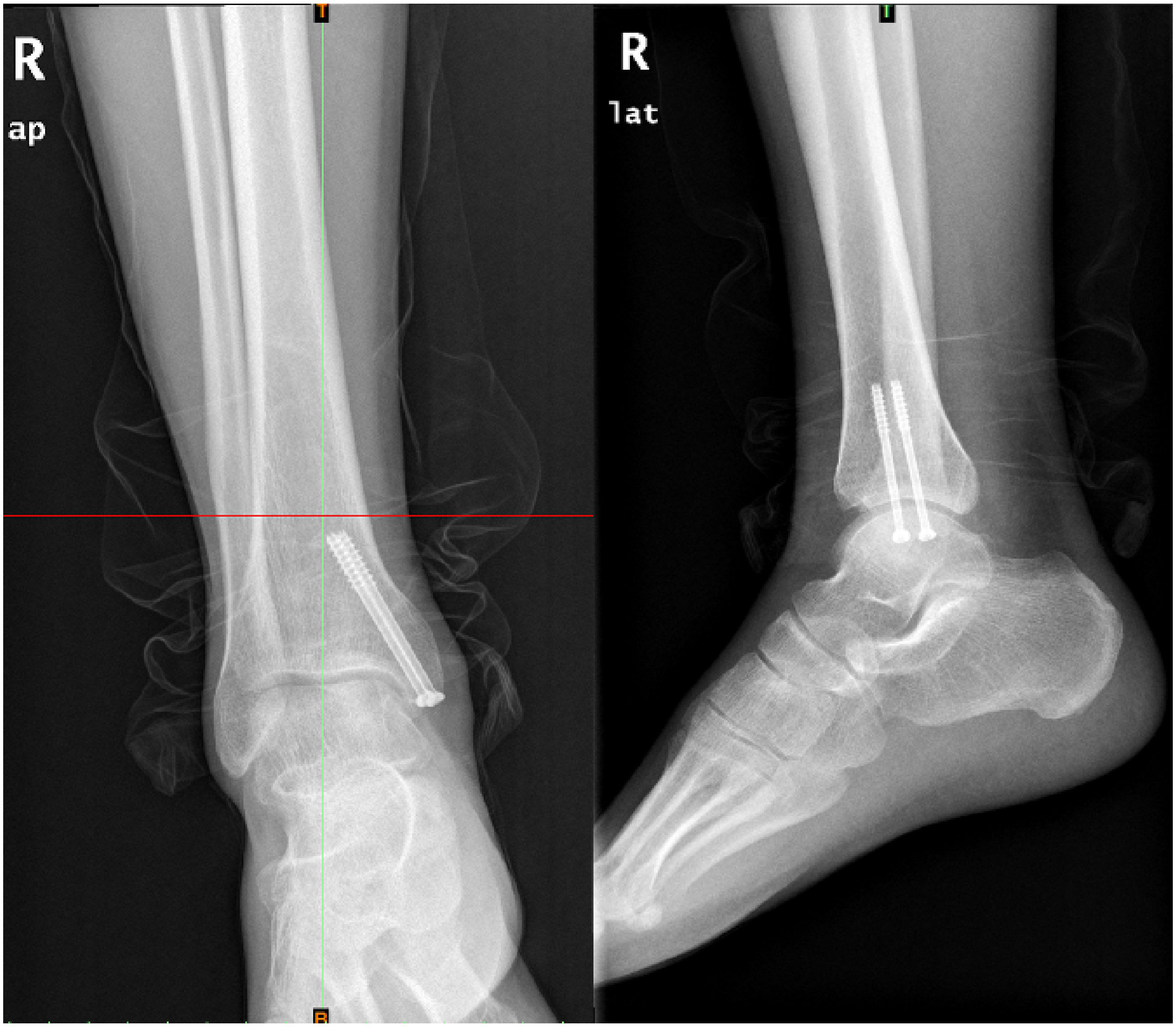
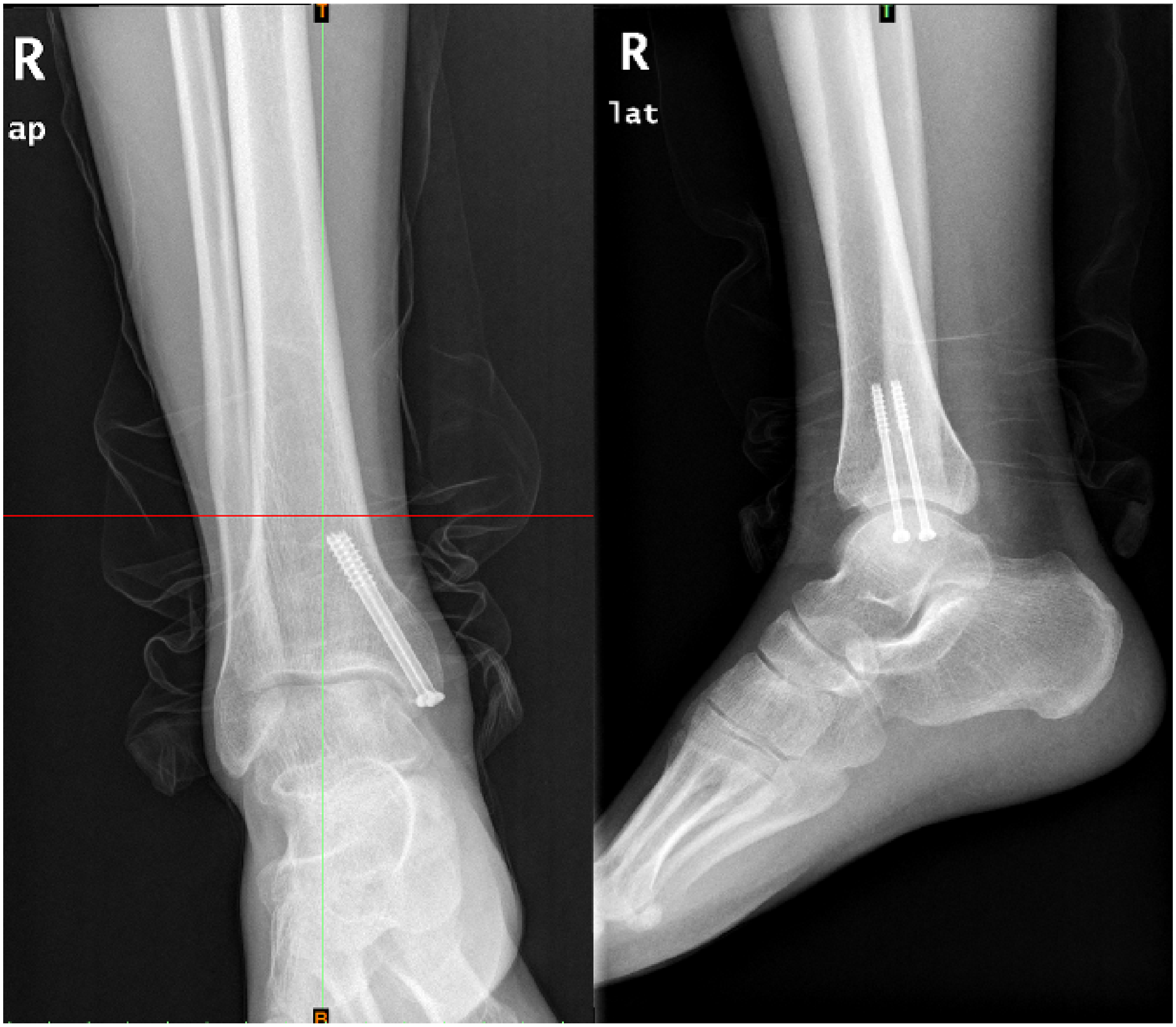


Figure 4

Twelve months after the fixation. Fractures healed with no displacement and no screw breakage



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