NAVIGATED FOOT & ANKLE SURGERY

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A goal without a plan is just a wish

- Antoine de Saint-Exupery

Foreword and Purpose for this book

In 2007 the University Hospitals of Geneva, under the initiative of Pierre Hoffmeyer, Head of the Department of Surgery and President of the European Federation of Orthopaedics and Traumatology (EFORT), acquired the first O-Arm™ navigation system in Switzerland in the belief that this would be a major step forward in our knowledge base. This humble beginning led to the introduction of the O-Arm™ in Foot & Ankle surgery very shortly thereafter. We explored its strengths, possibilities, limitations and practical aspects in our domain.

A number of surgeons joined our team with the desire to critically evaluate the potential of this new art in clinical use.

This book represents the efforts of many interested surgeons and we hope we have built a foundation for further work.

The authors would like to thank the following surgeons for their outstanding effort on making such a project a reality: Drsse Lisca Drittenbass, Dr Victor Dubois-Ferriere, Dr Axel Gamulin, Dr Francesco Pagano, Dr Ash Chowdhary, Dr Voon Chin Leow.

Definitely, it is a major step along the way to the use of new technology to improve patient outcome.

PD Dr. Mathieu Assal
Swiss Foot & Ankle Society
Immediate Past President

CONTENTS*

COMPUTER-ASSISTED ORTHOPAEDIC SURGERY (CAOS)

Introduction

Computer-assisted orthopaedic surgery (CAOS) is a real-time navigation guidance that supports surgeons during orthopaedic cases. The use of navigation guidance helps to increase precision, is less invasive and helps to achieve the surgical goal as planned. Furthermore, it helps to reduce X-ray radiation exposure to surgeons and staff. It is performed in combination with the O-Arm™ intraoperative imaging, which provides intraoperative cone beam computed tomography (CBCT) scan and full 3D reconstructed images. The navigation system consists of a camera tracking unit, special adapted orthopaedic instruments with an integrated reference arrays, and a computer unit running a navigation software (StealthStation™).

Principles

Computer-assisted navigation makes use of optical tracking. Reflective spheres are fixed on trackers attached to instruments and to the patient's reference frame. Infrared light is emitted by LED sources towards the surgical field.

A camera with two lenses detects the position of the reflective markers attached to the instruments and triangulates their position in the space.

Thanks to the automatic registration of the patient anatomy, the position of the instruments on 3D images are precisely displayed. Throughout the navigated procedure, the navigation system receives the position of the instrument trackers and patient reference frame and can calculate their position in the 3D space.

The following surgical techniques are for illustrative purposes only. The technique(s) actually employed in each case will always depend upon the medical judgement of the surgeon exercised before and during the surgery as to the best mode of treatment for each patient.

Checklist

A: What is needed for surgery?

Spheres – reflective markers

Patient reference set: including 2.2 mm K-wires to anchor the frame to bone

Pointer and Stealth-Midas™

Universal instrument adapter: enables any rigid instrument to be navigated

Navigated instruments

Note: Patient reference set must be opened for all cases. Different navigation instrument sets are available and can be used based on the surgical need.

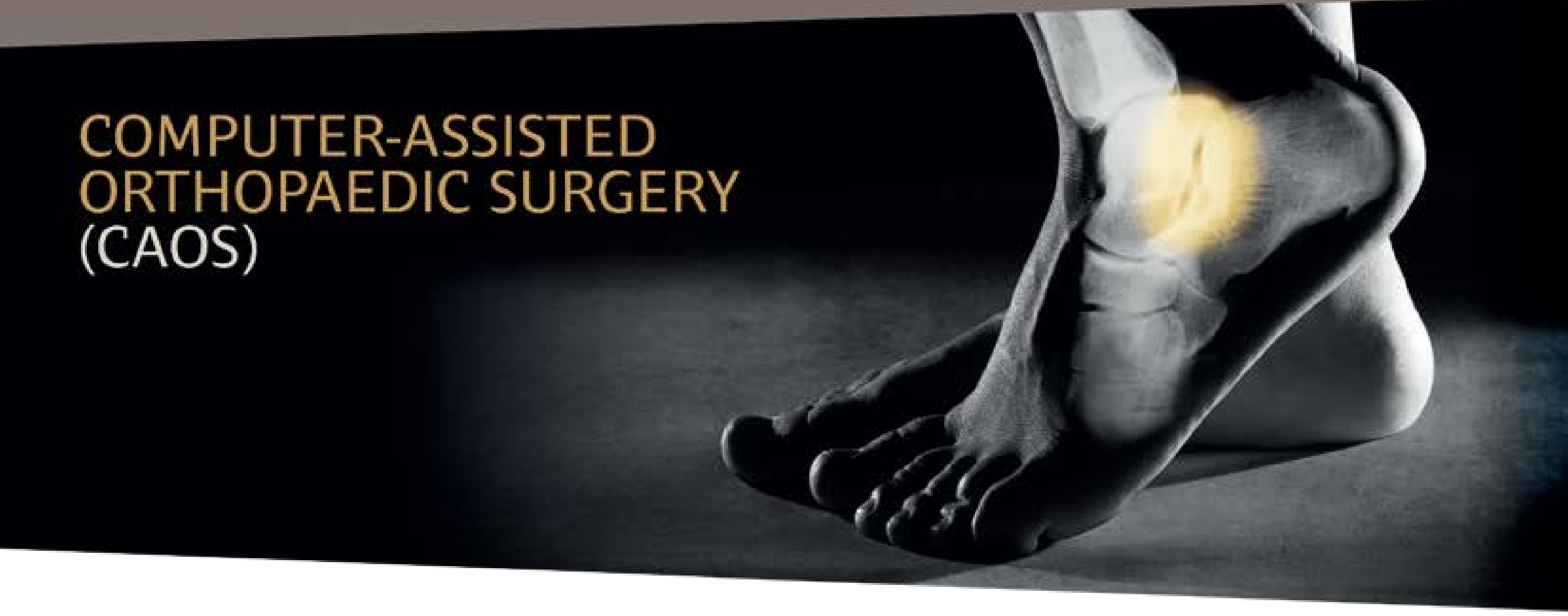
B: Power-on navigation and imaging system

Ensure the connection between systems is working. Choose the surgery type based on imaging modality and instruments. Check that the instruments on the table match the procedure type and instruments on the software.

Set-Up

A: Patient reference positioning is a key step to successful CAOS surgery.

1. Patient reference frame must be tightly assembled and rigidly anchored in a bone that is motionless respective to the area of surgery. If the frame moves in relation to the anatomy after registration, coordinates shift and accuracy is lost. The following chapters describe the optimal placement of the patient reference frame for each procedure type.
2. The line of sight between the camera, patient reference frame and instruments must be clear. Ensure nothing is obstructing the view of the camera. As illustrated below, place the reference frame between the area of surgery and the camera so that it does not interfere with the visibility of the instruments.



COMPUTER-ASSISTED ORTHOPAEDIC SURGERY (CAOS)

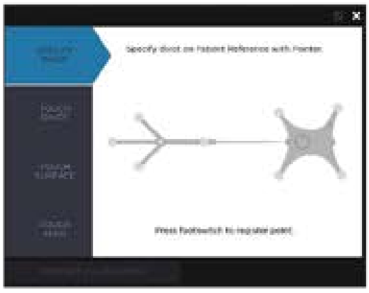
B: With patient reference frame correctly positioned, acquire a 3D CBCT scan

Before acquiring the 3D scan, centre the anatomy using laser alignment and control correct positioning with a lateral and anterior–posterior 2D fluoroscopy with the O-Arm™ cone beam CT (CBCT). Position the camera to see both the patient reference frame and imaging device trackers, and then perform the 3D scan. Images are automatically transferred to the navigation system. To obtain the best imaging–dose relationship, we recommend using device presets. By acquiring a 3D scan, all planes will be oriented automatically for the navigated instrument.

C: Instrument calibration

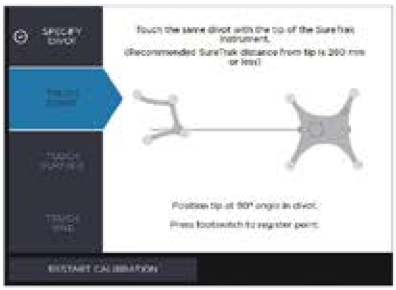
There are two types of instruments used for navigation:

1. Predefined instruments are those with built-in trackers. Their geometry and design is pre-configured in the software and only requires verification before use. This is accomplished by placing the instrument tip on the patient refrence frame divot.
2. A universal instrument adapter tracker is needed for non-predefined instruments. The tracker is firmly attached to the instrument to allow for any rigid instrument to be navigated. The instrument length and trajectory is then calibrated in a four-step calibration procedure, as demonstrated below.



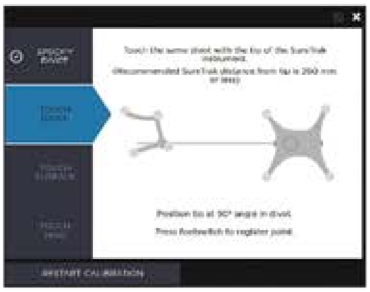
Step 1:

Specify the divot to be used for calibration with the pointer on the reference frame:



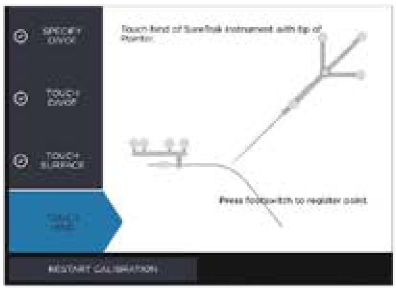
Step 2:

Touch the same divot with the instrument to be calibrated and memorise the length of the instrument.



Step 3:

Touch the surface just outside the divot to confirm the previous step.



Step 4:

Indicate the direction of the instrument by touching it with the pointer.

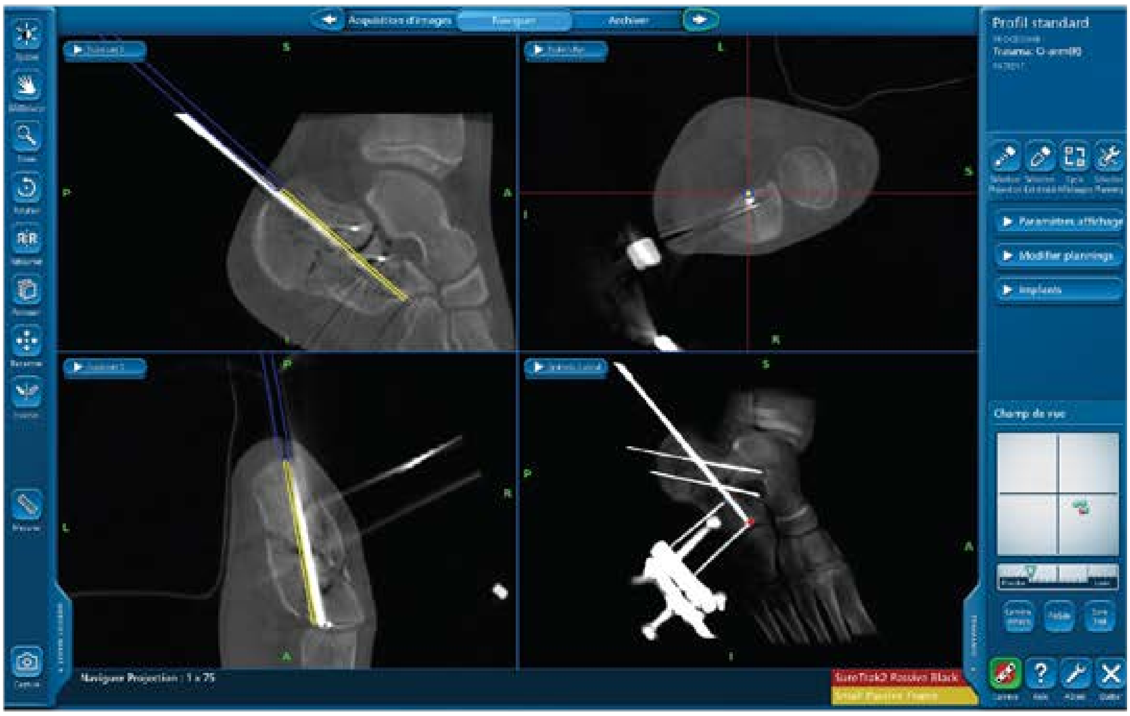
Navigation

The acquired images can be displayed as multi-planar reconstruction on the navigation system.

Finding the right trajectory is key for an optimal surgical outcome. Therefore the StealthStation navigation offers two planning options: pre-planning on the 3D dataset or planning during the surgery.

1. Preplanning on the 3D dataset:
    - Optimal entry and target point can be defined on the 3D images to define the optimal trajectory. Fine adjustment can be done via a mouse or the StealthStation Touchscreen.
2. Planning during the surgery.
    - Virtual projection (yellow) can be added as positive or negative extension to any instrument (displayed in blue). Projections can be saved and used as plans on the image. Length and width of the tip extension can be fine-tuned using the software.

In addition virtual measuring device can be used to define the implant size directly on the screen.



Pitfalls

Always keep in mind that you are working on a virtual image and that navigation accuracy can be lost. Thus, keep a critical judgment on what you see and frequently check accuracy on known anatomical landmarks or establish checkpoints for this purpose. Do not use the patient reference frame as a landmark for verification and be aware of two principal risks:

1. The patient reference frame moves in relation to the anatomy. The user should avoid touching it during the surgery.
2. The universal instrument tracker might become loose during surgery.

If accuracy is lost during the procedure, a new 3D scan can be acquired to re-establish the surgical setting.

FIBULA MALUNION: OSTEOTOMY AND FIXATION

Clinical history

40-year-old man presents with a Weber B ankle fracture healed with posterior subluxation of the fibula. CT scan shows a tibiofibular joint incongruency with malunion of the posterior malleolus (laterally translated in the incisura fibularis) and of the fibula (Figure 1a, 1b). The fibula is shortened by 7 mm with external rotation as compared to the contralateral side.

Surgical challenges

Recreation of the original fracture line with restoration of anatomy and physiological function of the ankle.

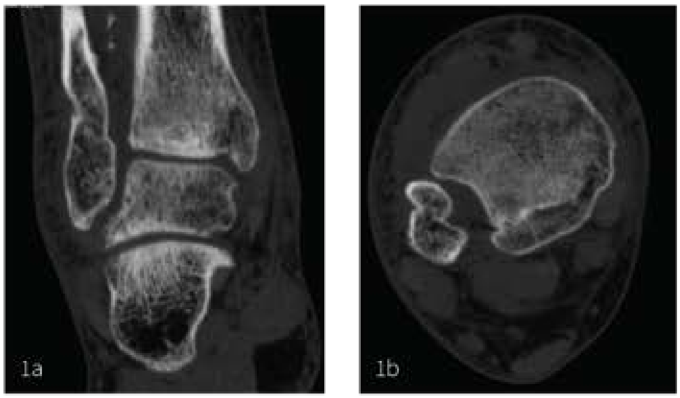


Figure 1: CT scan showing the injury, a) Coronal view; b) Sagittal view

Intervention

1. Osteotomy of the fibula through the original fracture line
2. Lengthening, rotation and anterior translation of the distal fibula
3. Osteosynthesis of the fibula with one-third tubular plate

Navigation

The osteotome is navigated to visualise its trajectory and ensure perfect accuracy in recreating the original fracture line. Additionally, the syndesmotic screws are navigated.

Surgical tactic

Step 1: Reference frame positioning

Patient is in the supine position. Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed to the medial malleolus (Figure 2) to avoid any undue movement relative to the surgical site. The reference frame is facing upwards where the camera is positioned (Figure 3).


Figure 2: K-wire fixation


Figure 3: Position of the reference frame.

Step 2: CBCT scan acquisition

Intraoperative CT scan is acquired after satisfactory positioning and fixation of the reference frame (Figure 4). Prior to the CT scan, the O-Arm™ is used as fluoroscopy to assure the K-wire fixation.

Step 3: Instrument calibration

The osteotome is calibrated on the frame to be navigated trough the original fracture line.

Step 4: Navigating the osteotomy

The osteotomy of the fibula recreates the original fracture with the help of a navigated osteotome (Figure 5).


Figure 4: Fluoroscopy prior to the 1st intraoperative CT scan


Figure 5: Intraoperative CT scan showing the recreation on the original fracture line

Step 5: Post-operative results

Standard weight-bearing radiographs show good restoration of the ankle mortise and fibular length (Figure 6a, b).

Figure 6: Postoperative standard radiographs;
a) Ankle AP view; b) Ankle lateral view.

ACUTE SYNDESMOTIC DISRUPTION WITH WEBER C ANKLE FRACTURE: REDUCTION AND FIXATION[1]

Clinical history

42 year-old man presents with a Weber C ankle fracture with posterior subluxation of the fibula. CT scan shows a tibiofibular joint incongruency without posterior malleolus injury (Figure 1a, 1b).

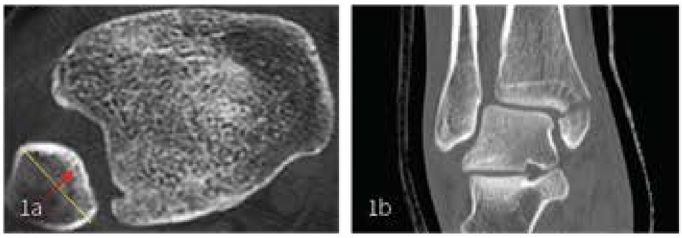
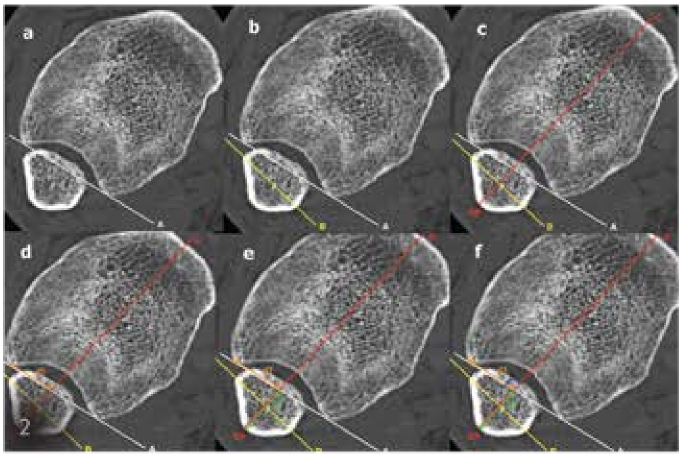


Figure 1a: CT images 10 mm proximal to the tibiotalar joint, showing unreduced syndesmosis and trajectory of reduction (red arrow); b) Coronal view showing the syndesmotic gap and a medial malleolar fracture.

Figure 2: Axial CT images of intact control ankle, 10 mm proximal to the tibiotalar joint. References parameters are determined and will serve as guide for navigation; a) Line A from the anterior to the posterior tubercle of the fibular incisura of the tibia; b) Line B between the anterior and posterior tubercles of the distal fibula; c) Line C perpendicular to line B passing through the midpoint between the fibular tubercles. The point where line C crossed the external cortex of the fibula was designated the fibular entry point (EP); d) Line d1, the anterior-posterior position of the fibula relative to the tibia determined by the distance from the anterior tubercle of the tibia to the point where line C crossed line A; e) Line d2, the medial-lateral position of the fibula in relation to the tibia determined by the distance from the fibular entry point to the point where line C crossed line A; f) The angle between line A and line C (AC angle) determined the rotation of the fibula relative to the tibia.

Surgical challenges

Reduction and fixation of the fibula in the incisura with restoration of anatomy and physiological function of the ankle (Figure 2a-f).



Intervention

1. Open reduction of the fibula in the incisura
2. Internal fixation of the fibula via a 4 cortical full threaded screw
3. Open reduction and internal fixation of the medial malleolus via 2 full threaded screws

Navigation

The fibula is navigated as described per Dubois-Ferrière V, Gamulin A, Chowdhary A, Fasel J, Stern R, Assal M.[1], as well as the drill bit and the syndesmotic screws.

1. V. Dubois-Ferrière, et al., Syndesmosis reduction by computer-assisted orthopaedic surgery with navigation:Feasibility and accuracy in a cadaveric study, Injury (2016), http://dx.doi.org/10.1016/j.injury.2016.10.009

Surgical tactic

Step 1: Reference frame positioning

Patient is in the supine position. Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed to the medial malleolus (Figure 3) to avoid any undue movement relative to the surgical site. The reference frame is facing upwards where the camera is positioned (Figure 4).

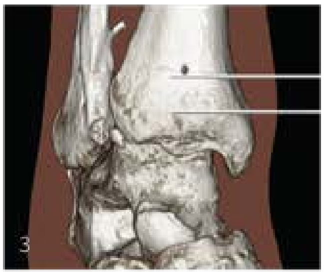


Figure 3: K-wire fixation

Figure 4: Position of the reference frame.

Step 2: CBCT scan acquisition

Intraoperative CT scan is acquired after satisfactory positioning and positioning of the reference frame. Prior to the CT scan the O-Arm™ is used as fluoroscopy to assure the K-wire fixation

Step 3: Instrument calibration

The fibula is navigated through a calibrated 2.5 mm K-wire. This is followed by calibration of the drill bit to allow for accurate syndesmotic screw placement

Step 4: Navigating the drilling trajectory

Navigation of the fibula and the drill bit gives optimal results as it permits an exact calculation of thetrajectory and length needed for the syndesmotic screw (Figure 5).

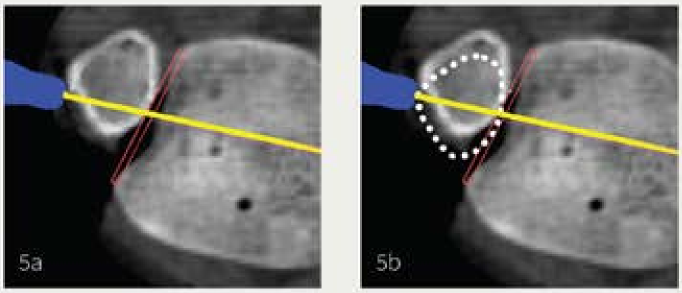


Figure 5: a) Real-time view of axial image during computer-assisted navigation showing the tip of the navigated drill guide (in blue) and the virtual trajectory of the K-wire (yellow) aligned with the predefined trajectory (C); b) Although the navigated wire has moved the fibula to its reduced position (dotted line), the actual movement of the fibula cannot be visualized on the navigation screen.

Step 5: Post-operative results

Standard weight-bearing radiographs show good restoration of the ankle mortise (Figure 6a, 6b).

Figure 6: Postoperative standard radiographs;
a) Ankle AP view; b) Ankle lateral view.

CALCANEAL FRACTURE: MINIMAL INVASIVE OSTEOSYNTHESIS

Clinical history

Calcaneus tongue-type fracture (Figure 1a, 1b) in a young gymnast following a fall from a height in practice.

Surgical challenges

Minimal invasive calcaneal osteosynthesis is a challenging procedure in terms of fracture reduction, restoration of anatomy and screw fixation.

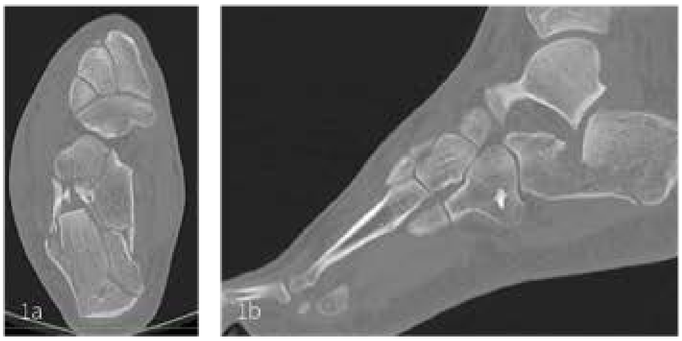


Figure 1: CT scan of the right calcaneal fracture; 1a: Axial view; 1b: Sagittal view.

Intervention

1. Reference frame positioning and 3D scan
2. Placement of 4.0 mm Schanz pin to be used as a joystick for the reduction of the tongue fragment (Figure 2)
3. Fracture reduction and preliminary fixation, followed by intraoperative 3D scan
4. Minimal invasive osteosynthesis with aid of intraoperative navigation

Navigation

1. Navigation of the Schanz pin allows accurate placement in the centre of the tongue fragment
2. Identification of the entry points
3. Visualisation of the trajectory
4. Calculation of the screw length

Figure 2: Accurate Schanz pin placement with navigation.

Surgical tactic

Step 1: Reference frame positioning

Patient in lateral decubitus position. Two 1.6 mm K-wires are inserted through the base of the reference frame. They are fixed to the plantar lateral aspect of the calcaneus, parallel to the floor (Figure 3a, 3b) to avoid any movement relative to the surgical site. The reference frame is facing upwards and along the tibial axis.

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and fixation of the reference frame. Intraoperative CBCT scan is then acquired.

Step 3: Instrument calibration

The power drill is calibrated using the universal adapter as explained in the introduction.

Calibration of the power drill on the reference frame is followed by verification of navigation accuracy and identification of the different entry points.

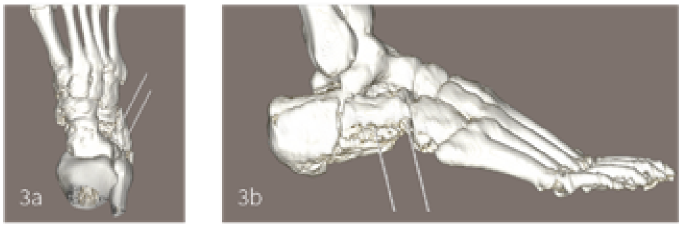


Figure 3: K-wire pin insertion; 3a: AP view; 3b: Lateral view.

Step 4: Navigating the Schanz pin

Navigation of Schanz pin on the power drill allows for accurate entry point selection. This entry point should be at the proximal tip of the calcaneal tuberosity just below the dorsal cortex (Figure 2, 4).

Step 5: Fracture reduction

Reduction manoeuvre of the tongue fragment with the Schanz pin used as joystick. The fracture is preliminarily fixed by 1.6 mm K-wires. O-Arm™ is then used as fluoroscope to assess fracture reduction (Figure 5). An intraoperative scan should be obtained to assure anatomic reduction (Figure 6).

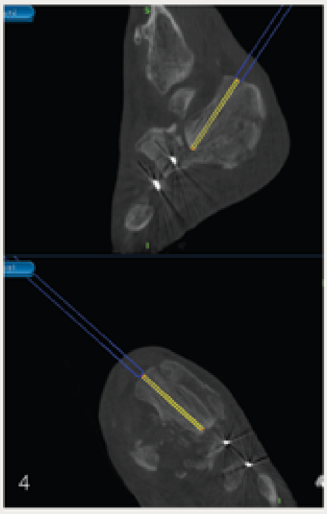


Figure 4: Schanz pin placement

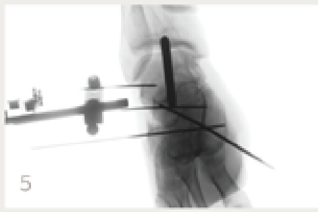


Figure 5: Intraoperative fluoroscopy.

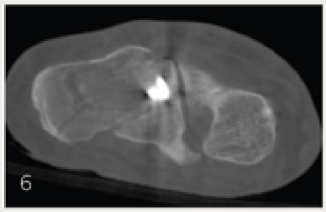


Figure 6: Intraoperative CBCT scan.

Step 6: Navigating the screws

Navigating the screws as they are placed allows for optimal results. It permits an exact calculation of the length and trajectory for each screw while avoiding any unintentional damage to adjacent joints or neighbouring structures on the medial side.

Minimum of three screws are mandatory to secure the posterior facet. In the coronal plane, the screw of the posterior facet should be inserted as a lag screw (a home run screw going to the sustentaculum tali). Other screws should secure the tongue to the tuberosity in the sagittal plane and additional screws are to be placed as necessary depending on the location of the remaining fracture lines.

Step 7: Post-operative result

Standard weight-bearing radiographs (Figure 7a, 7b) show restoration of hindfoot height and normal calcaneal width. Patient is completely healed and has returned to normal activities of daily living and full gymnastics.

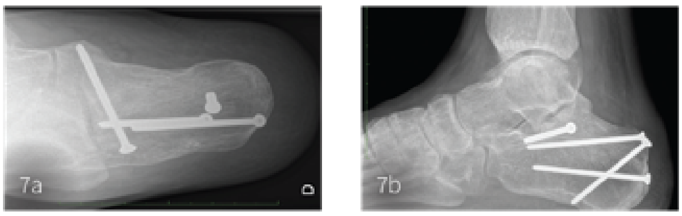


Figure 7: One-year post-operative standard weight-bearing radiographs; 7a: Calcaneus axial view; 7b: Foot lateral view.

CALCANEUS MALUNION: OSTEOTOMY THROUGH THE FRACTURE LINE AND SUBTALAR FUSION

Clinical history

Malunion in varus and loss of height of the hindfoot one-year post-nonoperative treatment of a joint depression calcaneal fracture (Figure 1a, 1b).

Surgical challenges

The challenge in this case is to perform the osteotomy through the original fracture line (primary fracture line) in order to regain hindfoot height and alignment.

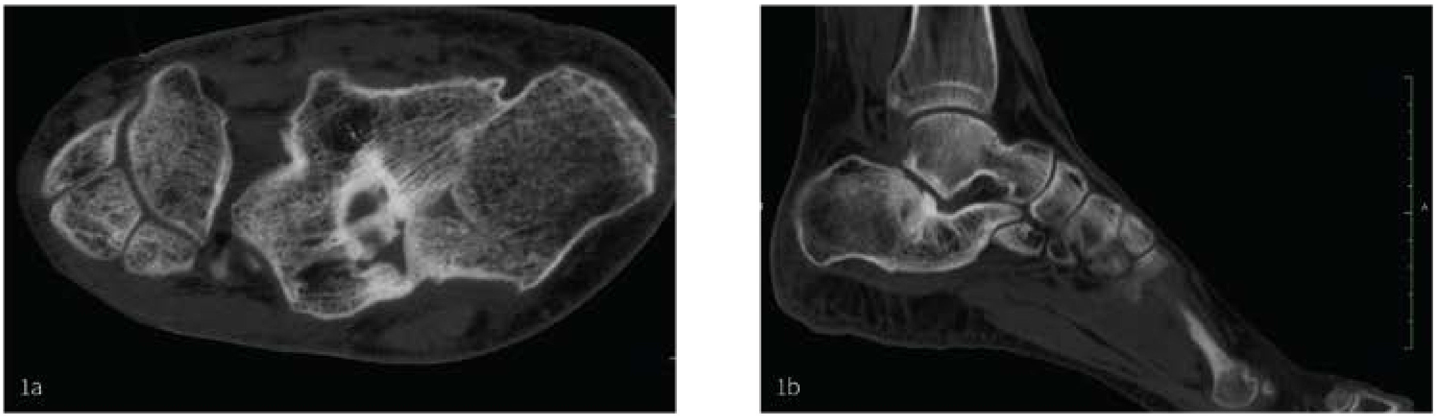


Figure 1: CT scan of the malunited calcaneal fracture; 1a: Axial view; 1b: Sagittal view.

Intervention

1. Osteotomy of the calcaneus through the original fracture line
2. Subtalar joint fusion

Navigation

To regain normal height, width and alignment of the hindfoot, the following were navigated:

1. The osteotome through the primary fracture line
2. The drill bit to define screw trajectory for osteotomy fixation and subtalar fusion

Surgical tactic

Step 1: Reference frame positioning

Patient in lateral decubitus position. Two 1.6 mm K-wires inserted through the base of the reference frame and fixed to the neck of the talus to avoid any undue motion (Figure 2). The reference frame is facing upwards and towards the head of the patient where the camera is positioned (Figure 3).

Figure 2: K-wire insertion.

Figure 3: Reference frame positioning.

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and fixation of the reference frame. Intraoperative CBCT scan is then acquired.

Step 3: Instrument calibration

The osteotome is calibrated using the adapter as explained in the introduction.

Calibration of the power drill on the reference frame is followed by verification of navigation accuracy and identification of the entry points for the subtalar arthrodesis screws.

Step 4: Navigating the osteotome

Navigation of the osteotome allows for accurate entry point selection and exact recreation of the primary fracture line (Figure 4a, 4b, 4c).

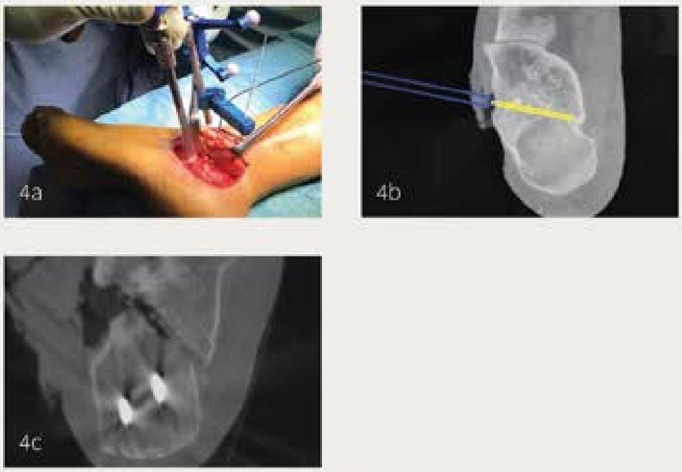


Figure 4: a) Defining the entry point of the osteotome;
b) Navigation trajectory on the CT scan (Blue line: entry point; Yellow line: trajectory and length); c) Axial image of the osteotomy

Step 5: Subtalar arthrodesis

The subtalar joint is prepared and filled with cancellous bone graft taken from the ipsilateral distal tibia.

Step 6: Navigating the screws

Navigated placement of the screws allows for optimal results. It permits an exact calculation of the length and trajectory for each screw while avoiding any damage to the adjacent joints.

A minimum of two screws are mandatory to secure osteotomy and fusion sites.

Step 7: Post-operative results

The post-operative standard radiographs show the restoration of hindfoot height and normal calcaneus width (Figure 5a, 5b). Patient is completely healed and has returned to normal activities of daily living and manual labour work.

Figure 5: One-year post-operative standard weight-bearing radiographs;
5a: Calcaneus axial view; 5b: Foot lateral view.

Chapter 5

CALCANEUS ANTERIOR PROCESS NONUNION: FRAGMENT RESECTION

Clinical history

A 37-year-old woman with persistent pain following a foot sprain. Nonoperative treatment modalities were only modestly successful. A diagnosis of nonunion is confirmed by SPECT CT scan (Figure 1).

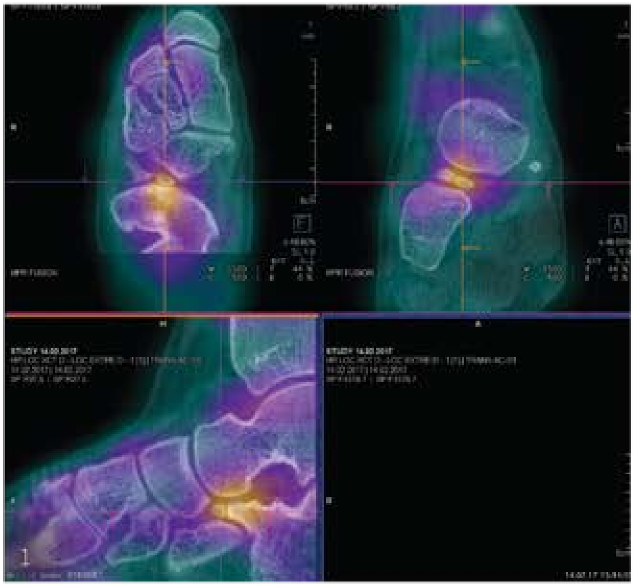


Figure 1: SPECT CT showing a high uptake at the nonunion site.

Surgical challenges

The ununited fragment is located deep at the junction level of the four Chopart bones in the midfoot.

1. Surgical access is difficult
2. It might not be possible to fully remove the bone fragment
3. It might result in damage to neighbouring structures

Intervention

1. Define the best surgical approach
2. Localise the fragment with the navigation
3. Resection of the fragment using the navigated instruments

Navigation

To obtain access to the anterior process of the calcaneus, the universal pointer is navigated.

Surgical tactic

Step 1: Reference frame positioning

Patient is in the supine position. Two 1.6 mm K-wires inserted through the base of the reference frame and fixed to the posteromedial aspect of the calcaneus to avoid any undue motion relative to the intervention site (Figure 2). The reference frame is facing upwards and medially where the camera is positioned (Figure 3).

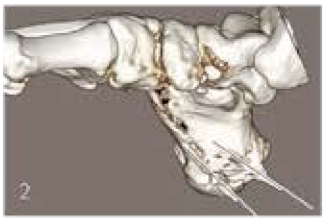


Figure 2: K-wire insertion.

Figure 3: Reference frame positioning.

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and fixation of the reference frame. Intraoperative CBCT scan is then acquired.

Step 3: Navigating the pointer

Navigating the universal pointer allows for entry point identification and clear access to the fragment with minimal trauma (Figure 4a, 4b).

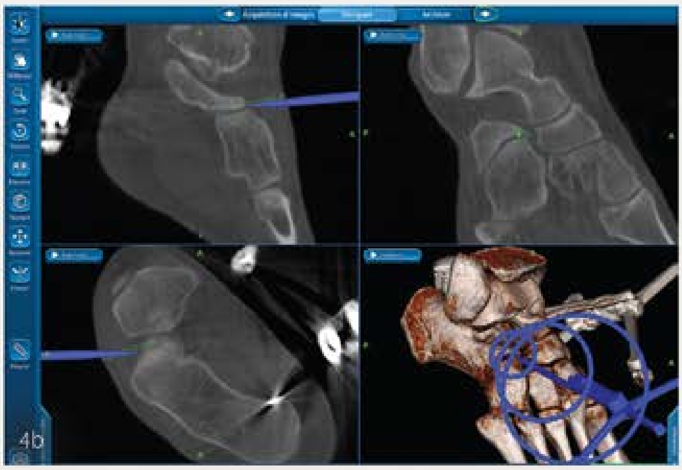


Figure 4a: Pointer use at the surgical site; 4b: Localisation of the ununited fragment using the pointer as seen on the CBCT scan.

Step 4: Site preparation and fragment resection

The site is prepared via a minimal incision through the sinus tarsi and the fragment is resected under continuous visualisation with the navigated pointer.

Step 5: Post-operative results

Intraoperative CBCT scan showed complete excision of the fragment (Figure 5a, 5b). The patient is asymptomatic and back to work and full physical activities.

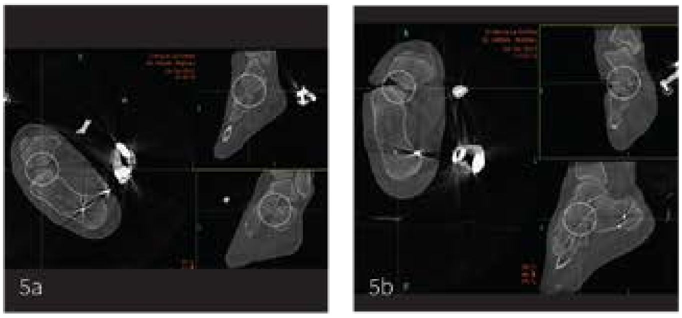


Figure 5: CBCT scan showing the pseudarthritic fragment site pre- and post-operatively;
5a: CBCT scan showing the fragment site preoperatively;
5b: CBCT scan showing the same site post fragment excision.

CALCANEONAVICULAR COALITION: FUSION OF THE COALITION

Clinical history

Symptomatic congenital coalition of the calcaneonavicular (CN) joint in a 26-year-old woman (Figure 1). Nonoperative treatment resulted in only modest success.

Figure 1: Series of different axis SPECT CTs with a clear uptake at the coalition site and cysts on the navicular.

Surgical challenges

1. Fusion site débridement and grafting
2. Selection of the appropriate entry point
3. Trajectory and length of the screw
4. Major complication is to have the screw in an adjacent joint (e.g., talonavicular)

Intervention

1. CN joint (coalition) débridement
2. Fusion site preparation with graft
3. Obtain perfect screw position and fixation

Navigation

Navigation allows for:

1. Identification of the entry points
2. Visualisation of the trajectory
3. Calculation of optimal screw length

Surgical tactic

Step 1: Reference frame positioning

Patient is in the supine position. Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed to the medial aspect of the navicular (target bone) to avoid any undue motion (Figure 2a, 2b). The reference frame is facing upwards and laterally where the camera is positioned (Figure 3).

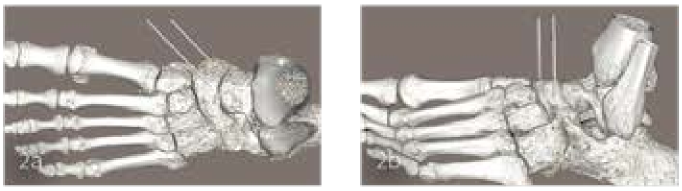


Figure 2: K-wire positioning; 2a: Foot AP; 2b: Foot lateral oblique.

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and fixation of the reference frame. Intraoperative CBCT scan is then acquired.

Figure 3: Reference frame positioning.

Step 3: Instrument calibration

The universal pointer and the power drill are calibrated using the universal instrument adapter as explained in the introduction.

Step 4: Site preparation

A reamer is used to break the coalition and prepare the CN fusion site (Figure 4) with the help of the navigated universal pointer. A cancellous bone graft is obtained from the distal ipsilateral tibia.

Figure 4 : Minimal invasive preparation of the bone

Figure 5a: Guide wire insertion

Step 5: Navigating the guide wire and screw placement

The guide wire is navigated and a cannulated partially threaded screw is placed in a minimal invasive way (Figure 5a, 5b) under continuous visualisation of the trajectory (Figure 6).

Figure 5b: Minimal invasive screw placement.

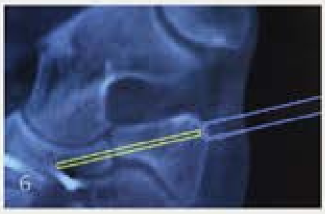


Figure 6: Navigation trajectory on the CBCT scan (blue line: entry point; yellow line: trajectory and length).

Step 6: Post-operative results

Simulated weight-bearing standard radiographs show perfect screw positioning and length (Figure 7a, 7b). The patient is asymptomatic at one-year post-operative follow-up and the foot scan shows a fully healed CN fusion.

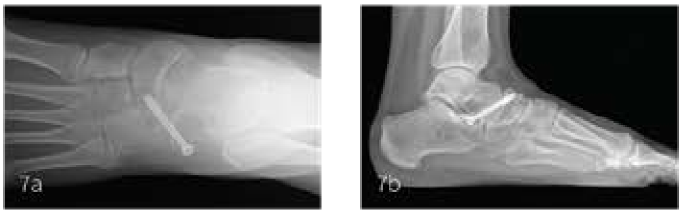


Figure 7: Post-operative standard simulated weight-bearing radiographs; 7a: Foot AP view; 7b: Foot lateral view.

NAVICULAR SPLIT FRACTURE: MINIMAL INVASIVE OSTEOSYNTHESIS

Clinical history

A 47-year-old woman with a foot injury. Standard radiographs show a navicular fracture (Figure 1). CT scan shows a Sangeorzan II fracture (Figure 2a, 2b).

Surgical challenges

The special shape of the navicular and its place in the midfoot makes minimal invasive reduction and internal fixation a challenging procedure. The risk of damaging neighbouring structures is high, especially the talonavicular (TN) joint.

Figure 1: Standard foot lateral view radiograph.

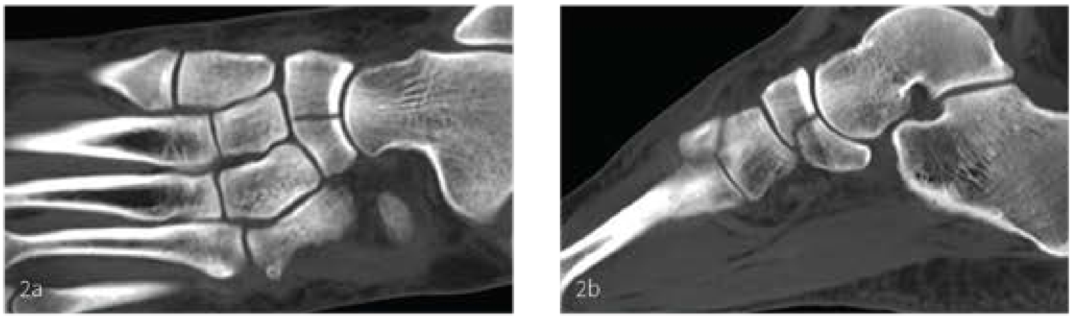


Figure 2: CT scan; 2a: Coronal view showing the articular involvement; 2b: Sagittal view.

Intervention

Minimal invasive reduction and internal fixation by a single screw.

Navigation

The power drill is navigated to obtain accurate:

1. Entry point
2. Trajectory
3. Screw length calculation

Surgical tactic

Step 1: Reference frame positioning

Patient is in the supine position. Two 1.6 mm K-wires inserted through the base of the reference frame and fixed to the dorsomedial aspect of the first ray (first pin in the first cuneiform and the second pin in the first metatarsal) (Figure 3a, 3b). The frame is then fixed away from the previewed drilling site. Care is taken intraoperatively to avoid any movement relative to the surgical site so as not to compromise the accuracy of the navigation. The reference frame is facing downwards and away from the patient's head where the camera is positioned (Figure 4).

Figure 3: K-wire fixation;
3a: AP view; 3b: Lateral view.

Figure 4: Position of reference frame.

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and fixation of the reference frame. Intraoperative CBCT scan is then acquired.

Step 3: Instrument calibration

The universal pointer and the power drill are calibrated using the adapter as explained in the introduction.

Step 4: Entry point verification

Due to the banana shape of the navicular, entry point identification is crucial. The use of the universal pointer allows for optimal entry point identification (Figure 5). It should be as perpendicular as possible to the fracture line and its trajectory within the bone should be long enough to secure fixation of the fracture while avoiding any neighbouring joint penetration.

Step 5: Navigating the drilling trajectory

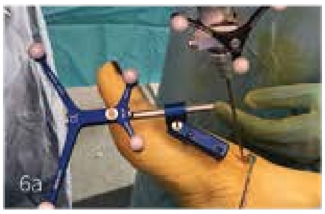
The navigated drill bit helps identify the optimal trajectory (Figure 6a, 6b).

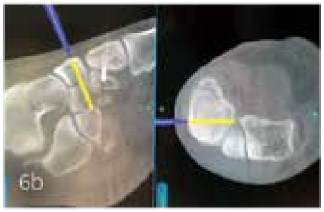
Step 6: Screw placement

A cannulated partially threaded screw is placed in a minimal invasive way (Figure 7).

Step 7: Post-operative results

Post-operative radiographs at one year show anatomical reduction, perfect screw positioning and consolidation of the fracture (Figure 8a, 8b). Clinical examination reveals good motion and patient is back to daily activities.





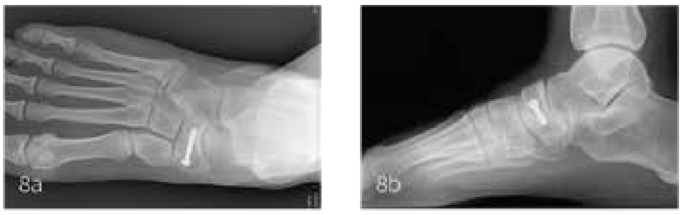


Figure 5: Entry point verification.
Figure 6: Intraoperative navigation; 6a: Power drill navigation; 6b: Navigation trajectory on the CBCT scan (blue line: entry point; yellow line: trajectory and length)
Figure 7: Minimal invasive screw placement.
Figure 8: One-year post-operative standard weight-bearing radiographs;
8a: AP view; 8b: Lateral view.

THIRD CUNEIFORM OSTEOID OSTEOMA: RESECTION

Clinical history

Painful lesion presumed to be an osteoid osteoma of the 3rd cuneiform of the left foot (Figure 1a, 1b) in a 18 year-old patient.

Surgical challenges

The challenge is exposure of the lesion without harm to surrounding structures.

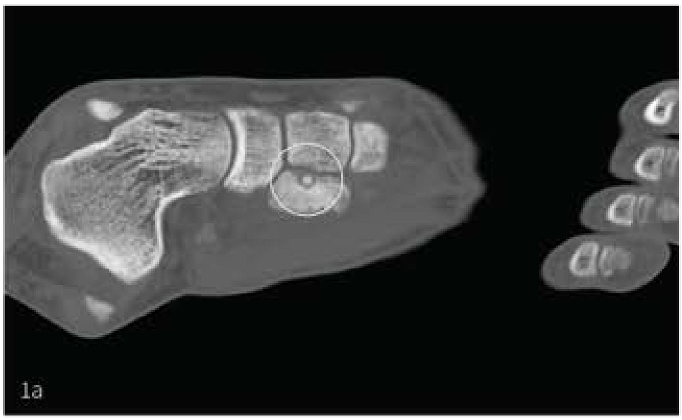


Figure 1: CT scan of the left foot; a) Axial view; b) Coronal view

Intervention

1. Lesion localisation
2. Minimal invasive excision through drilling and curettage

Navigation

1. Identification of the lesion
2. Visualisation of entry point and trajectory

Surgical tactic

Step 1: Reference frame positioning

Patient is in the supine position. Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed laterally to the base and shaft of the fifth metatarsal (Figure 2) to avoid any movement relative to the surgical site. The reference frame is facing away from the patient and upwards.

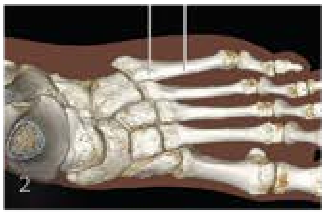


Figure 2: K-wire insertion

Figure 3: Reference frame positioning

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CT scan to ensure satisfactory position and positioning of the reference frame. Intraoperative CT scan is then acquired.

Step 3: Instrument calibration

The power drill is calibrated using the universal adapter as described in the introduction.

Calibration of the power drill on the reference frame followed by verification of navigation accuracy and identification of the entry point (Figure 4a, 4b).

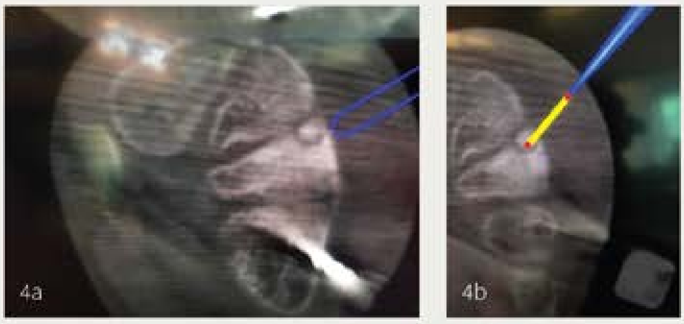


Figure 4: CT scan and navigation showing a) entry point; b) drilling trajectory

Step 4: Lesion resection

The calibrated drill bit is used to locate the lesion via a minimal incision dorsally. The lesion is then drilled out entirely (Figure 5) and sent for histological analysis. An intraoperative scan is obtained to ensure complete resection of the lesion.

Figure 5: The drill bit entry point

Step 5: Postoperative results

Intraoperative CBCT scan (Figure 6) shows complete removal of the lesion. Histology confirmed the lesion to be an osteoid osteoma.

Figure 6: Intraoperative CBCT shows complete removal of the lesion.

FIFTH METATARSAL BASE STRESS FRACTURE: INTRAMEDULLARY SCREW FIXATION

Clinical history

A 23-year-old professional dancer presents with a nonunion of a stress fracture at the level of the fifth metatarsal base. (Figure 1a, 1b), which failed 14 months of nonoperative treatment. The patient is handicapped by the symptomology of the nonunion site.

Surgical challenges

The identification of the entry point is critical due to the sigmoid shape of the bone.

Figure 1: CT scan showing the nonunion site 1a) Foot AP view; 1b) Foot sagittal view

Intervention

Intramedullary screw fixation of the fifth metatarsal with support by intraoperative navigation.

Navigation

To ensure perfect positioning of the intramedullary screw, the drill bit was navigated allowing for:

1. Identification of the entry point
2. Visualisation of the trajectory
3. Calculation of the screw length

Surgical tactic

Step 1: Reference frame positioning

The patient is in the lateral decubitus position. Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed to the distal-lateral aspect of the affected fifth ray (Figure 2, 3, 4a, 4b) to avoid any movement relative to the surgical site. The reference frame is facing up and posteriorly where the camera is positioned.

Figure 2: K-wire position in fifth metatarsal.

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory positioning and fixation of the reference frame (Figure 3). Intraoperative CBCT scan is then acquired.

Figure 3: Fluoroscopy showing the K-wire placement.

Step 3: Instrument calibration

To visualise the optimal trajectory for the fixation of this fracture, the power drill is navigated using an adapter.

1. Calibration of the power drill on the reference frame
2. Verification of navigation accuracy and identification of the entry point of the drill bit

Figure 4a, 4b: Frame and capture fixed.

Step 4: Navigating the guide wire and screw placement

The drilling trajectory is fully dependent on the accuracy of the entry point. The entry point has to be just medial to the tuberosity tip of the fifth metatarsal base at the dorsal upper third.

Once the guide wire is placed in the shaft, the wire is over-drilled and a 5.0 cannulated self-tapping and partially threaded screw is inserted (Figure 5a, 5b). The screw is usually 50 mm long.

Figure 5a: Guide wire placement; 5b: Screw fixation.

Step 5: Post-operative results

Standard weight-bearing radiographs show consolidation of the fracture site (Figure 6a, 6b). The patient went back to her professional activities.

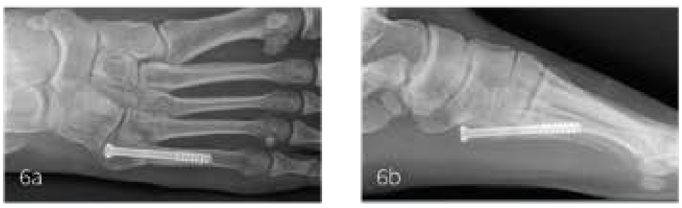


Figure 6: Standard post-operative radiographs; 6a: AP view; 6b: Lateral view.

Chapter 10

LISFRANC INJURY: MINIMAL INVASIVE LISFRANC JOINT FIXATION

Clinical history

Lisfranc injury (Figure 1) in a 58-year-old man due to a motorbike accident.

Surgical challenges

In Lisfranc joint injuries, surgical challenges include restoration of anatomy, fracture fixtation, joint reduction and avoidance of further soft tissue trauma. Some specific conditions can benefit from minimal invasive procedures by use of navigation.

Figure 1: Standard radiographs of the foot AP

Intervention

1. Preliminary reduction and fixation from the first cuneiform to the second metatarsal base (Lisfranc Joint), followed by intraoperative CBCT scan
2. Minimal invasive screw placement through the Lisfranc joint with aid of intraoperative navigation

Navigation

1. Identification of entry point
2. Visualisation of trajectory
3. Calculation of screw length

Surgical tactic

Step 1: Reference frame positioning

Patient is placed in the supine position. Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed dorsally to navicular (Figure 2) to avoid any movement relative to the surgical site. The reference frame is facing upwards and lateral.

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and positioning of the reference frame. Intraoperative CBCT scan is then acquired.

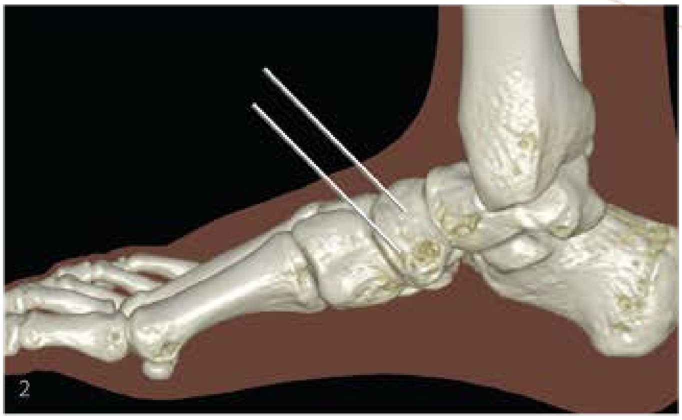


Figure 2: K-wire insertion

Step 3: Instrument calibration

The power drill is calibrated using the universal adapter as described in the introduction.

Calibration of the power drill on the reference frame followed by verification of navigation accuracy and identification of the entry point.

Step 4: Lisfranc joint reduction

Preliminary reduction and fixation is achieved by the use of pointed reduction forceps. O-Arm™ is then used as fluoroscope to assess the fracture (Figure 3). An intraoperative scan is obtained (Figure 4).

Figure 3: Intraoperative fluoroscopy

Figure 4: Intraoperative CBCT scan

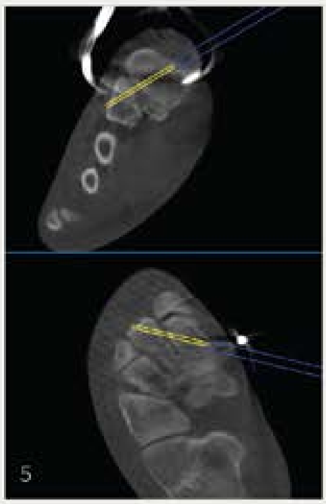


Figure 5: Navigation screen showing real time navigation on three plans

Step 5: Screw placement

Navigating the screw allows optimal placement in a minimal invasive fashion. It optimises screw trajectory by defining optimal entry point and target point, thus permitting an exact calculation of the length while avoiding any damage to neighbouring structures (Figure 5).

Step 6: Postoperative results

Standard postoperative radiographs (Figure 6a, 6b) show restoration of anatomy and satisfactory fixation.

Figure 6: Post-operative standard radiographs; 6a: AP view; 6b: Lateral view.

FLATFOOT:
HINDFOOT FUSION

Clinical history

A 63-year-old man presents with a painful degenerative flatfoot (adult acquired flatfoot) (Figure 1a, 1b). Nonoperative treatment including immobilisation and footwear adaptation for over two years were modest in their efficacy.

Surgical challenges

In order to regain functionality, accurate alignment of the hindfoot is crucial. Careful preparation of the joints is important to allow optimal fusion success. Accurate screw placement is key.

Figure 1: Standard weight-bearing radiographs show the acquired flatfoot characteristics mainly the dorsolateral peritalar subluxation, 1a: Foot AP view; 1b: Foot Sagittal view

Intervention

1. Prepare the talonavicular joint
2. Prepare the subtalar joint
3. Bone graft to enhance fusion
4. Reduce the foot and stabilise the construct with temporary transarticular K-wires

Navigation

The power drill is navigated to ensure satisfactory screw placement in all axes.

Surgical tactic

Step 1: Articular surface preparation

The patient is placed in the supine position. The TN joint is prepared by removal of articular cartilage. The subtalar joint is prepared in a similar manner. A graft is used to enhance fusion.

Step 2: Reference frame positioning

Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed to the medial malleolus. Utmost care is taken to avoid any undue motion relative to the intervention site (Figure 2). The reference frame faces upwards and medial where the camera is positioned (Figure 3).

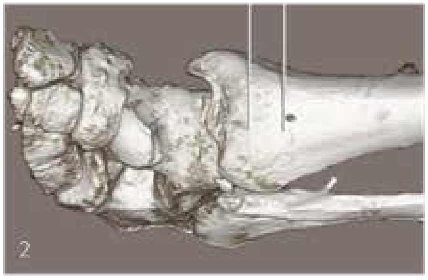


Figure 2: K-wire fixation. Figure 3: Reference frame positioning

Step 3: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and positioning of the reference frame. Intraoperative CBCT scan is then acquired.

Step 4: Instrument calibration

The power drill is calibrated using the adapter as described in the introduction (Figure 4).

Figure 4 : Power drill calibration

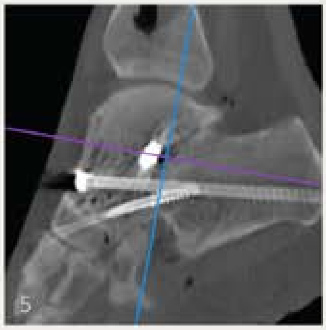


Figure 5: Intraoperative CBCT scan

Step 5: Power drill navigation and screw placement

The power drill is navigated providing optimal entry points, drilling trajectories and screw length calculations. A final CBCT scan is acquired, ensuring satisfactory foot reconstruction and screw fixation (Figure 5).

Step 6: Postoperative results

One-year follow up, standard weight-bearing radiographs show complete fusion (Figure 6a, 6b). The patient is asymptomatic and back to full physical activities.

Figure 6: One-year post-operative weight-bearing radiographs
6a: AP view; 6b: Lateral view

CHARCOT FOOT: MIDFOOT FUSION WITH BOLTS

Clinical history

A 70-year-old man with advanced neuroarthropathy of the midfoot (Charcot foot) including fragmentation of the navicular. Patient was previously operated in another medical facility and presents with nonunion at the subtalar and the talonavicular joints. Standard radiographs demonstrate hardware failure (Figure 1a, 1b).

Figure 1: Standard weight-bearing radiographs showing hardware failure; 1a: AP view; 1b: Lateral view.

Surgical challenges

1. Poor-quality bone and multiple nonunion sites
2. Medial arch collapse (loss of plantigrade foot)
3. Intramedullary implant positioning with midfoot fusion bolt

Intervention

Complex reconstruction of the foot:

1. Hardware removal
2. Resection of the fragmented (necrotic) navicular bone
3. Autograft (cortical strut and cancellous bone) taken from the ipsilateral tibia
4. Medial column retrograde intramedullary screw (midfoot fusion bolt)
5. Plate and screws augmentation

Navigation

To secure the multilevel fusion and obtain satisfactory foot restoration, the following steps are supported by navigation:

1. Entry points and trajectory
2. Guidewire for the medial column bolt
3. Measurement of bolt length

Surgical tactic

Step 1: Nonunion sites débridement and foot realignment

Patient is in the supine position. Hardware is removed. Fragmentation of the navicular is addressed (removal of most of the necrotic navicular) and the subtalar joint is débrided. The first cuneometatarsal joint is prepared for fusion. The foot is realigned in the three planes. Multiple temporary K-wires are inserted in order to lock the plantigrade position.

Step 2: Reference frame positioning

Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed to the dorsomedial aspect of the talar head and neck to avoid any undue motion relative to the intervention site (Figure 2). The reference frame is facing upwards and medial where the camera is positioned (Figure 3).

Step 3: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and fixation of the reference frame. An intraoperative CBCT scan is then acquired.

Step 4: Instrument calibration

The cannulated bolt wire is calibrated using the adapter as described in the introduction.

Step 5: Navigating the cannulated bolt wire

The entry point at the level of the first metatarsal head is identified by the projected navigation line that passes through the first metatarsal shaft longitudinal axis, the centre of the talar head and the centre of the talar dome sagittal radius (a straight Meary line). Screw length can be precisely measured (Figure 5).

Step 6: Graft harvest and placement

The 8 x 1 cm cortical strut is harvested from the ipsilateral proximal tibia and placed in a carved split along the medial aspect of the foot medial column (Figure 6a, 6b).

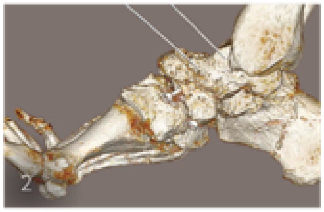
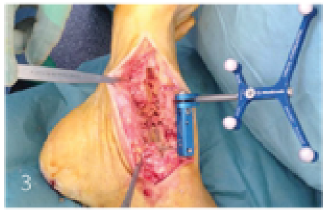



Figure 2: K-wires insertion. Figure 3: Reference frame positioning.

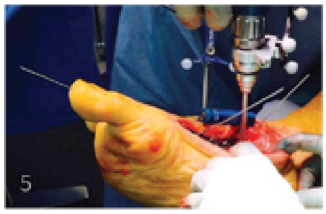



Figure 4: Fluoroscopy of the reference frame positioning. Figure 5: Calibrated power drill use.

Step 7: Medial column intramedullary bolt insertion

The bolt is inserted after drilling along the bolt wire.

Step 8: Construct augmentation with medial column plate

A long and thick medial column plate is used to augment the strength of the construct. An additional K-wire is inserted through the MTP1 joint in order to force the joint in plantar flexion. This will relieve the soft tissue tension at the level of the planetarly placed entry point of the bolt. K-wire is removed at 2 weeks.

Step 9: Post-operative results

Standard radiographs show restoration of the foot medial arch (Figure 7a, 7b).

Figure 6a: Cortical bone harvest from the ipsilateral tibial; 6b: Strut placement.

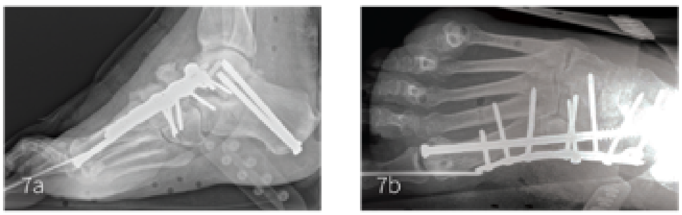


Figure 7: Post-operative standard radiographs; 7a: AP view; 7b: Lateral view.

TALUS POSTERIOR FACET FRACTURE: MINIMAL INVASIVE FIXATION

Clinical history

A 39-year-old man sustained a motorvehicle accident and presented with a posterior talar body fracture (Figure 1).

Figure 1: Sagittal view CT showing the fracture site.

Surgical challenges

Minimal invasive reduction and fixation of such a fracture carries several challenges:

1. Surgical access
2. Reduction of fracture
3. Compression fixation
4. Damage to neighbouring structures

Intervention

1. Define the best surgical approach
2. Localise the entry point
3. Screw placement

Navigation

For accurate screw placement, the power drill is navigated.

Surgical tactic

Step 1: Reference frame positioning

Patient is placed in the prone position. Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed to the posterior aspect of the tibia. Utmost care is taken to avoid any undue motion relative to the intervention site (Figure 2). The reference frame is facing upwards and medial towards the camera (Figure 3).

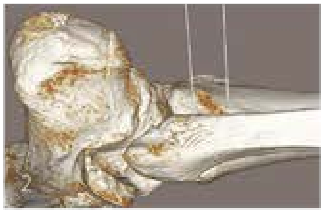


Figure 2: K-wire insertion. Figure 3: Reference frame positioning.

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and fixation of the reference frame. An intraoperative CBCT scan is then acquired.

Step 3: Instrument calibration

The power drill is calibrated using the adapter as described in the introduction.

Step 4: Navigating the pointer

Navigating the universal pointer allows for entry point identification and clear access to the fragment with minimal soft tissue trauma (Figure 4).

Step 5: Navigating the drill bit

The site is prepared via a minimal posteromedial incision, and the fracture is fixed using a fully threaded screw placed under compression supported by continuous visualisation (Figure 5).

Figure 4: Localisation of the fragment using the pointer as seen on the scan.
Figure 5: Navigated drill bit

Step 6: Post-operative results

Intraoperative CBCT scan shows satisfactory screw placement and fracture compression. One-year follow-up, standard weight-bearing radiographs show excellent results (Figure 6a, 6b). Patient is asymptomatic and back to work and full physical activities.

Figure 6: One-year post-operative weight-bearing standard radiographs; 6a: Ankle AP view; 6b: Ankle lateral view.

TALUS HEAD SPLIT FRACTURE: MINIMAL INVASIVE OSTEOSYNTHESIS

Clinical history

Talar head and neck split fracture (Figure 1) in a 39-year-old patient.

Surgical challenges

Minimal invasive osteosynthesis is a challenging procedure in terms of fracture reduction, anatomy restoration and screw fixation. In this case, no fracture reduction is necessary as the fracture is minimal displaced which means it needs compression and stability. This management is particularly in the settings of an intra-articular facture as this bone heals by first intention therefore requiring absolute stability.

Figure 1: CT scan of the left foot and ankle; Coronal view

Intervention

1. Fracture preliminary fixation, followed by intraoperative 3D scan
2. Minimal invasive osteosynthesis with aid of intraoperative navigation

Navigation

1. Navigation of the guidewire allows for its accurate placement
2. Identification of entry point
3. Visualisation of trajectory
4. Calculation of screw length

Surgical tactic

Step 1: Reference frame positioning

Patient is placed in the supine position. Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed medially to the tibial metaphysis and the talar body (Figure 2) as to avoid any movement relative to the surgical site.
The reference frame is facing upwards and lateral.

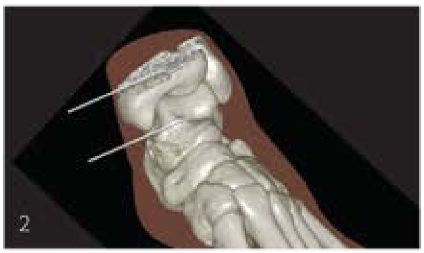


Figure 2: K-wire insertion: lateral view

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CT scan to ensure satisfactory position and positioning of the reference frame (Figure 3). Intraoperative CT scan is then acquired.

Figure 3: Fluoroscopy showing the reference frame positioning

Step 3: Instrument calibration

The power drill is calibrated using the universal adapter as described in the introduction.

Step 4: Fracture fixation

Preliminary fixation is by 2.0 mm K-wires. O-Arm™ is then used as fluoroscope to assess the fracture. An intraoperative scan is obtained.

Step 5: Navigating the screws

Navigating the drill bit allows for optimal results in a minimal invasive fashion. A 2.4 mm screw is then placed as lag screw.

This step permits for an exact trajectory visualisation while avoiding any unintentional damage to neighboring structures and allowing for screw length calculation.

Intraoperative CBCT shows perfect screw placement (Figure 4).

Figure 4: Intraoperative CBCT

Step 6: Post-operative results

Postoperative standard radiographs (Figure 5a, b) show restoration of anatomy and satisfactory fixation.

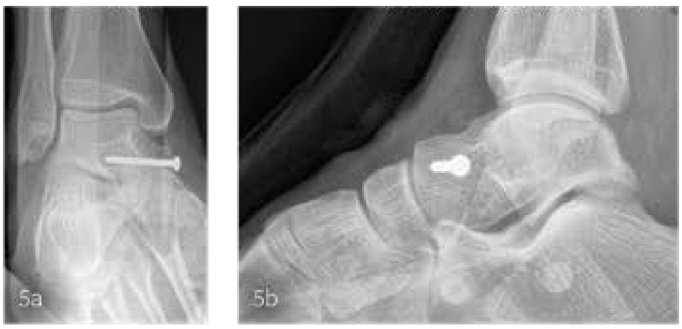


Figure 5: Postoperative standard radiographs; a) AP view; b) Lateral view.

PILON FRACTURE: POSTERIOR PLATING

Clinical history

A 40-year-old woman sustained an ankle injury. A pilon type B fracture is confirmed by CT scan (Figure 1a, 1b).

Surgical challenges

Combined posterior and medial column fractures. Reduction and fixation of a posterior malleolus fracture can be challenging due to the limited vision field. Accurate screw placement close to the tibiofibular joint and to the tibiotalar joint can be challenging. Anatomic reduction of the joint surface and rigid fixation of the fractures are essential in order to optimise outcome.

Figure 1: CT scan of the ankle; 1a: Axial view; 1b: Sagittal view.

Intervention

1. Modified posteromedial approach with patient placed in the prone position
2. Open reduction and internal fixation of the posterior malleolus
3. In the supine position, open reduction and internal fixation of the medial malleolus through an anteromedial approach

Navigation

The screws of the posterior plate need to be as close as possible to the tibiotalar joint and to the fibular incisura (lateral screw) but not through it. The power drill is navigated to ensure satisfactory fixation of the posterior plate screws in terms of trajectory and length.

Surgical tactic

Step 1: Posterior malleolus open reduction

Patient is placed in the prone position and the modified posteromedial approach is used. The fracture site is prepared and the impacted articular fragment is anatomically reduced. The fracture is temporarily fixed with 1.6 mm K-wires.

Step 2: Reference frame positioning

Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed to the tibia posteriorly, above the fracture site to avoid any undue motion relative to the intervention site (Figure 2). The reference frame is facing upwards and laterally where the camera is positioned (Figure 3).

Step 3: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and fixation of the reference frame. An intraoperative CBCT scan is then acquired.

Step 4: Instrument calibration

The power drill is calibrated using the adapter as described in the introduction.

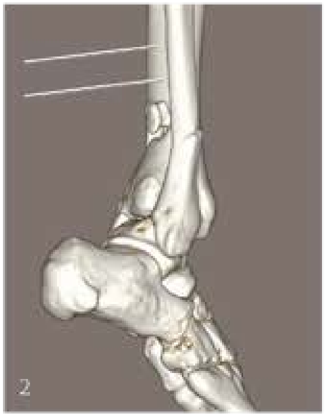
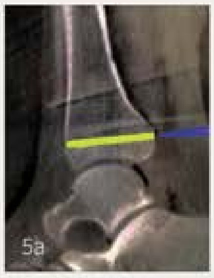


Figure 2: K-wire insertion. Figure 3: Reference frame positioning.

Step 5: Power drill navigation and screw placement

An anatomical posterior plate is used and placed as distal as possible. Compression screws through the plate are placed as close as possible to the tibiotalar joint and to the fibular incisura (lateral screw) avoiding any joint penetration. The power drill is navigated (Figure 4) allowing for continuous visualisation of the drilling trajectory and screw length calculation (Figure 5a, 5b). After adequate irrigation, the site is closed plane by plane.



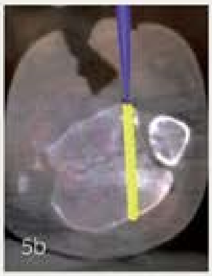


Figure 4: Navigated power drill use.
Figure 5: Navigation trajectory on the CBCT scan (blue line: entry point; yellow line: trajectory and length); 5a: Sagittal view; 5b: Coronal view.

Step 6: Medial malleolus open reduction and internal fixation

The patient is turned to the supine position. Medial malleolus is then reduced through an anteromedial approach and fixed with an anti-glide plate and screws.

Step 7: Post-operative results

An intraoperative CBCT scan shows anatomic reduction and restoration of the articular surface. A one-year follow-up, standard radiographs show complete consolidation and absence of arthrosis (Figure 6a, 6b). The patient is asymptomatic and back to work and full physical activities.

Figure 6: One-year post-operative full-weight-bearing radiographs; 6a: AP view; 6b: Lateral view.

PILON OSTEOCHONDRAL LESION: RETROGRADE GRAFTING

Clinical history

A 16-year-old girl with a painful ankle following a minor trauma that was self-treated as a simple ankle sprain. Patient presents at three months post-injury with persistent pain. Imaging studies showed a cystic osteochondral lesion (Figure 1a, 1b). Nonoperative treatment including immobilisation and footwear adaptation for over two years were modest in their efficacy.

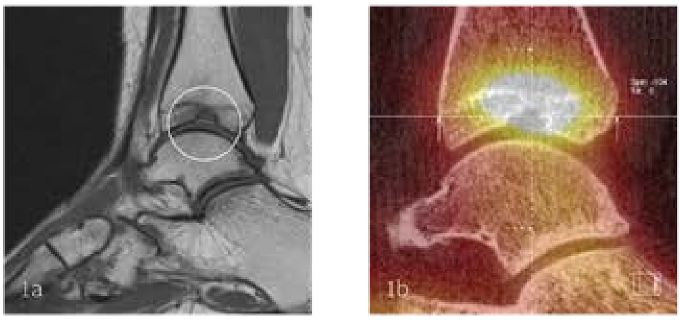


Figure 1: Imaging studies; 1a: Ankle MRI shows a distal tibial osteochondral lesion combined with a cyst; 1b: Ankle SPECT CT shows a high uptake zone at the lesion site.

Surgical challenges

1. Access to the lesion site without disturbing the ankle joint
2. Adequate débridement and filling of the cyst
3. Accurate autograft impaction exactly at the level of the bone cyst without violation of the tibiotalar joint

Intervention

1. Tibial tunnel allowing for bony lesion access
2. Curettage and débridement of the bone cyst
3. Cancellous bone graft impaction harvested at the ipsilateral proximal tibia

Navigation

The power drill is navigated to ensure correct entry point, drilling trajectory and depth.

Surgical tactic

Step 1: Reference frame positioning

The patient is in the supine position. Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed anteriorly to the distal tibia to avoid any undue motion relative to the intervention site (Figure 2). The reference frame is upwards and facing the patients head where the camera is positioned (Figure 3).


Figure 2: K-wire fixation.


Figure 3: Reference frame positioning.

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory position and fixation of the reference frame. An intraoperative CBCT scan is then acquired.

Step 3: Instrument calibration

The power drill is calibrated using the adapter as described in the introduction.

Step 4: Power drill navigation

The power drill is navigated allowing for optimal entry point (50 mm above the tip of the medial malleolus), the drilling trajectory is determined as well as its depth. The entry point is identified and a 4.5 mm drill bit is used to create the tunnel leading to the cyst (Figure 4).

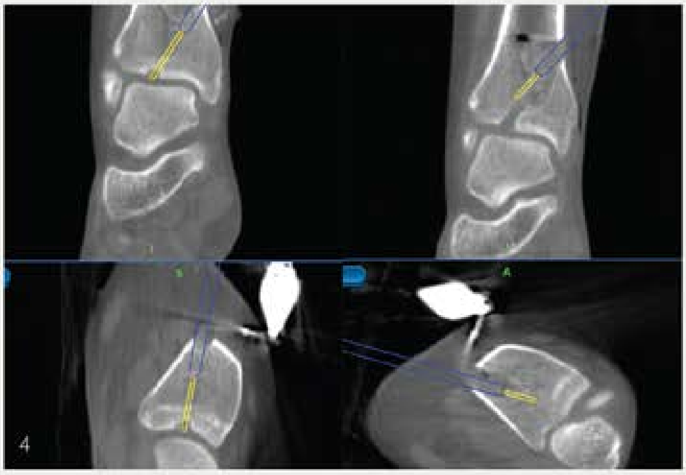


Figure 4: Navigation of the tunnel drilling as seen on the screen.

Step 5: Lesion débridement

The cyst is débrided without violation of the talar side of the joint. Cancellous bone graft is harvested from the ipsilateral proximal tibia and then impacted deep in the tunnel. A CBCT scan is obtained to confirm adequate filling of the cyst site and a smooth articular surface.

Step 6: Post-operative results

At one-year follow-up, the patient is asymptomatic and back to full physical activities (Figure 5a, 5b).


Figure 5: One-year post-operative CT scan, 5a) Coronal view; 5b) Sagittal view

TIBIAL PLATEAU: MINIMAL INVASIVE OSTEOSYNTHESIS

Clinical history

Tibial plateau fracture, Shatzker I (Figure 1) in a 62 year-old patient.

Surgical challenges

Minimal invasive osteosynthesis is a challenging procedure in terms of fracture reduction, anatomy restoration and screw fixation.

Figure 1: Standard radiographs of the left knee; AP view

Intervention

1. Fracture reduction and preliminary fixation, followed by intraoperative 3D scan
2. Minimal invasive osteosynthesis with aid of intraoperative navigation
3. Placement of 2 compression screws and an antiglide plate

Navigation

1. Navigation of the guide wires allows for their accurate placement
2. Identification of entry points
3. Visualisation of trajectory
4. Calculation of screw length

Surgical tactic

Step 1: Reference frame positioning

Patient is placed in the supine position. Two 1.6 mm K-wires are inserted through the base of reference frame and fixed to the anterior aspect of the proximal shaft of the tibia (Figure 2) to avoid any movement relative to the surgical site.

The reference frame is facing upwards and lateral.

Step 2: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CT scan to ensure satisfactory position and fixation of the reference frame. Intraoperative CT scan is then acquired.

Step 3: Instrument calibration

The power drill is calibrated using the universal adapter as explained in the introduction.

Calibration of the power drill on the reference followed by verification of navigation accuracy and Identification of the different entry points.

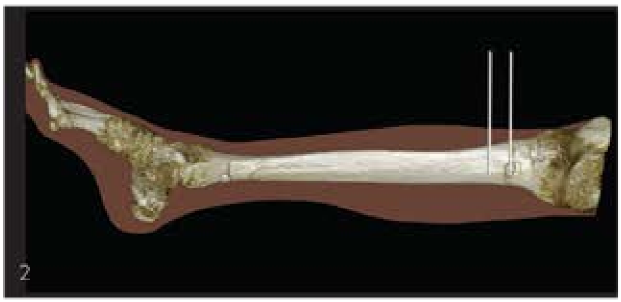


Figure 2: K-wire insertion: lateral view

Step 4: Fracture reduction and preliminary fixation

In Schatzker type I, there is a minimal need for joint reduction. Preliminary fixation is by 2.0 mm K-wires. O-Arm™ is then used as fluoroscope to assess the fracture.

Figure 3: CBCT showing the trajectory of the screws

Figure 4: CBCT showing the antiglide plate screw trajectory

Step 5: Navigating the screws

Navigating the screws as they are placed allows for optimal results in a minimal invasive fashion. It permits for optimal screws entry points as it secures the fracture fragment at its best place. The goal is to be as perpendicular to the fracture line as possible and to secure both the posterior and the anterior aspects of the fracture.

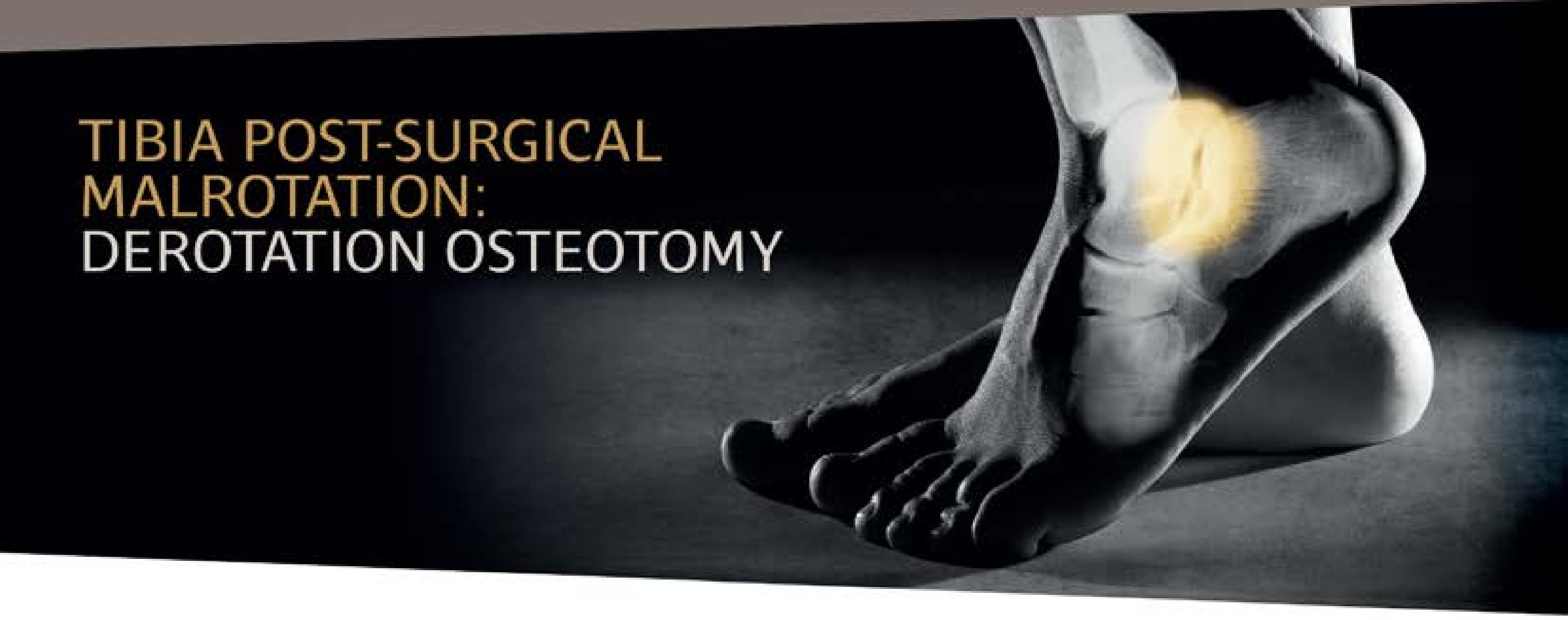
Navigation also allows for exact calculation of length and trajectory visualisation of each screw while avoiding any unintentional damage to neighboring structures on the medial side.

Minimum of 2 screws is mandatory to secure the fixation (Figure 3). A 1/3 tubular plate is used as antiglide and is inserted in a minimal invasive way and fixed with a single fully threaded bicortical screw (Figure 4).

Step 6: Post-operative results

Postoperative standard radiographs (Figure 5a, 5b) show restoration of anatomy and satisfactory fixation.

Figure 5: Postoperative standard radiographs; a) AP view; b) lateral view.



TIBIA POST-SURGICAL MALROTATION: DEROTATION OSTEOTOMY

Clinical history

A 63-year-old woman presents at six months post lower third tibial shaft fracture and intramedullary (IM) nail fixation (Figure 1a, 1b). Clinical examination revealed excess of external rotation of 26° of the distal tibia in relation to the proximal tibia when compared to the contralateral leg. This was further supported by a comparative CT scan.

Surgical challenges

1. Recreate the original fracture line
2. Exact internal derotation of 26°

Figure 1a, 1b, 1c, 1d: CT scan and clinical appearance demonstrating excess of an external rotation right leg measured at 26°.

Intervention

1. Fibula osteotomy
2. Tibial osteotomy through original fracture line
3. Distal tibia derotation around the IM nail
4. Lock the nail

Navigation

The distal tibia is navigated in relation to the proximal tibia where the reference frame is positioned. Navigation of the tracker fixed in the axial plane into the distal tibia ensures exact derotation of 26° around the axis.

Surgical tactic

Step 1: Minimal invasive osteotomy of the fibula

A percutaneous burr is used to achieve a minimal invasive osteotomy of the fibula.

Step 2: Tibial osteotomy

The IM nail is kept in place while the distal locking bolts are removed. An anteromedial approach is used over the original fracture site. A chisel is used to recreate the transverse fracture around the IM nail.

Step 3: Reference frame positioning

The patient is in the supine position. Two 1.6 mm K-wires are inserted through the base of the reference frame and fixed anteriorly into the proximal tibia just above the fracture line (Figure 2). The reference frame faces upwards and medial where the camera is positioned (Figure 3).

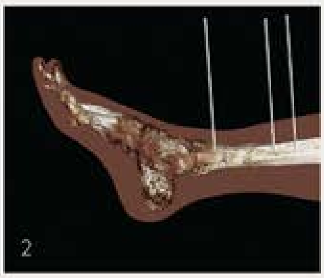


Figure 2: K-wire insertion. Figure 3: Reference frame positioning.

Step 4: CBCT scan acquisition

The O-Arm™ is used as a fluoroscope prior to the CBCT scan to ensure satisfactory positioning of the reference frame. An intraoperative CBCT scan is then acquired.

Step 5: Instrument calibration

A 2.5 mm K-wire is calibrated using the adapter as described in the introduction, and then carefully fixed to the distal tibia at the mid-malleolar distance using a light hammer (Figure 4). A tracker is then fixed on the K-wire allowing for tracking of the distal tibial axis when rotating.

Figure 4: To track distal tibia derotation, the whole distal segment is navigated using the tracker fixed to it with a 2.5 mm K-wire.

Step 6: Angle calculation, derotation and fixation

The navigation programme is used to create a 3D illustration showing the angle of rotation needed to achieve the desired axis correction (Figure 5a, 5b). When the correction is obtained, the osteotomy site is then secured by a two-hole 1/3 tubular plate (monocortical screws). The IM nail is locked distally with three locking bolts to ensure stability of the construct.

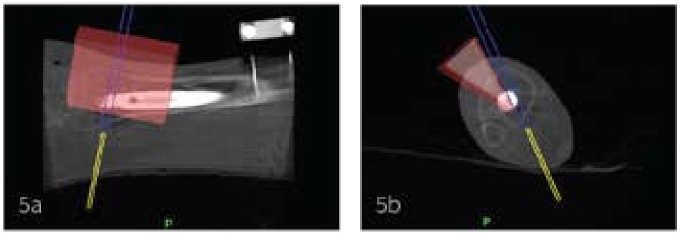


Figure 5a, 5b: The navigation screen showing the angle calculation and the tracking of the distal tibia.

Step 7: Post-operative results

Post-operative standard radiographs show satisfactory coronal alignment (Figure 6a, 6b). Clinical alignment is identical to the contralateral side.

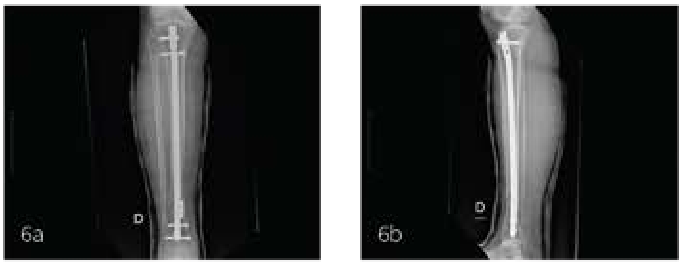


Figure 6: Post-operative radiographs; 6a: Leg AP view; 6b: Leg lateral view.

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*The following surgical techniques are for illustrative purposes only. The technique(s) actually employed in each case will always depend upon the medical judgement of the surgeon exercised before and during the surgery as to the best mode of treatment for each patient.

See the device manuals for detailed information regarding the instructions for use, indications, contraindications, warnings, precautions, and potential adverse events. For further information, contact your local Medtronic representative and/or consult the Medtronic website at medtronic.eu.