
2.1 Introduction

Foot and ankle surgery at the end of the twentieth century was characterized by the use of sophisticated computerized preoperative and postoperative diagnostic and planning procedures.^{13,39} However, intraoperative computerized tools that assist surgeons during their struggle for the planned optimal operative result are lacking. This results in an intraoperative “black box” without optimal visualization, guidance and biomechanical assessment.³⁹ In the future, this intraoperative “black box” will be opened, and we shall have more intraoperative tools to achieve the planned result.³⁹ Intraoperative three-dimensional imaging (ISO-C-3D/ARCADIS-3D), Computer Assisted Surgery (CAS) and Intraoperative Pedography are three possible innovations to realize the planned procedure intraoperatively.^{48,49}

2.2 Part 1: CAS Guided Retrograde Drilling in Talar Osteochondral Lesions (OCD)

The goal in the management of stages I and II osteochondral defects of the talus is revascularisation of the lesion.⁷ A debridement of the chondral part is required,^{3,62} limited to loose cartilage or cartilage with poor quality.^{3,59,62} Subchondral drilling of the lesion allows revascularisation. Retrograde drilling leaves the chondral surface intact, and may therefore be advantageous compared with antegrade drillings.¹⁶ Arthroscopically guided drillings are limited to those lesion that can be accessed arthroscopically.⁵⁹ In the remaining cases, open procedures are undertaken.⁵⁴ Based on these principles, CT based Computer Assisted Surgery (CAS) guided retrograde drilling of osteochondral lesions has been described with promising results.^{16,52} Computed tomography (CT)- and fluoroscopy-based navigation

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systems in current use are of limited flexibility.³⁸ On of the drawbacks of fluoroscopy are lack of three-dimensional imaging intraoperatively. CT-based navigation still requires intraoperative cumbersome registration, extra preoperative planning, and imaging with use of further technical resources.⁴³ In addition to the current method of arthroscopic evaluation and treatment, we earlier introduced an alternative technique of using 3D-imaging with ISO-C-3D (Siemens Medical Inc., Munich, Germany) based CAS guided retrograde drilling of the lesion.⁴³ This method was feasible, accurate and showed good clinical outcome.^{39,43} However, the technical equipment of the earlier 3D-imaging devices (model ISO-C-3D, Siemens Medical Inc., Munich, Germany) and CAS devices (Model Surgigate, Medivision Inc., Oberdorf, Switzerland & Northern Digital Inc., Waterloo, Ontario, Canada; Medivision later sold and renamed Praxim Inc., Grenoble, France) was cumbersome and error-prone.^{39,43} These devices were further developed for easier and faster handling, and were less prone to error. We introduce a 3D-imaging based CAS guided retrograde drilling with a combination of these modern devices (model ARCADIS-3D, Siemens Medical Inc., Munich, Germany, and model Navivision, Brainlab Inc., Heimstetten, Germany).

2.2.1

Clinical Example

An OCD stage II according to Berndt and Harty and stage IIa according Hepple/Winson at the talus was diagnosed (Fig. 2.1a–c)^{7,21,46} at imaging, and the diagnosis confirmed at arthroscopy (Fig. 2.2).⁴⁶ The cartilage was intact but softer than the surrounding cartilage. In the procedure, a Dynamic Reference Base (DRB) was fixed to the talar head through a small incision (Fig. 2.5a),⁴⁶ and an intraoperative image acquisition with ARCADIS followed (Figs. 2.3a–f).⁴⁶ The 2D-images were obtained to show the poor visibility of the OCD lesion on 2D images.^{11,43} Retrograde drilling was planned with a starting point at the lateral talar process, and an endpoint in the area of subchondral sclerosis beneath the intact cartilage (Fig. 2.4).⁴⁶ The drilling was performed with a 4.5 mm drill (Figs. 2.5a and b).⁴⁶ The subchondral sclerosis is removed during the drilling as part of the drilling floor. After the drilling, a 1 mm titanium Kirschner wire was inserted in the drill hole (Fig. 2.6),⁴⁶ and 2D- and 3D ARCADIS imaging was performed (Fig. 2.7).⁴⁶ Then, the Kirschner wire was removed and autologous cancellous bone graft harvested from the ipsilateral distal tibia was inserted. Arthroscopy confirmed the intact and stabilized cartilage after drilling and bone grafting. The time needed for the entire procedure was 45 min. The radiation contamination is comparable to 104 pulsed digital fluoroscopic images or 42 s pulsed fluoroscopic imaging. Figures 2.8a and b⁴⁶ show MRI images at 2 year-follow-up with intact cartilage and an incorporated bone graft.

2.2.2

Results

Fifty-two patients with symptomatic talar OCD Stadium I and II were included in a clinical follow-up study. Time needed for preparation, including the placement of the DRB, scanning time and preparation of the trajectories was 7 min 32 s (4–30 min). In 50 patients

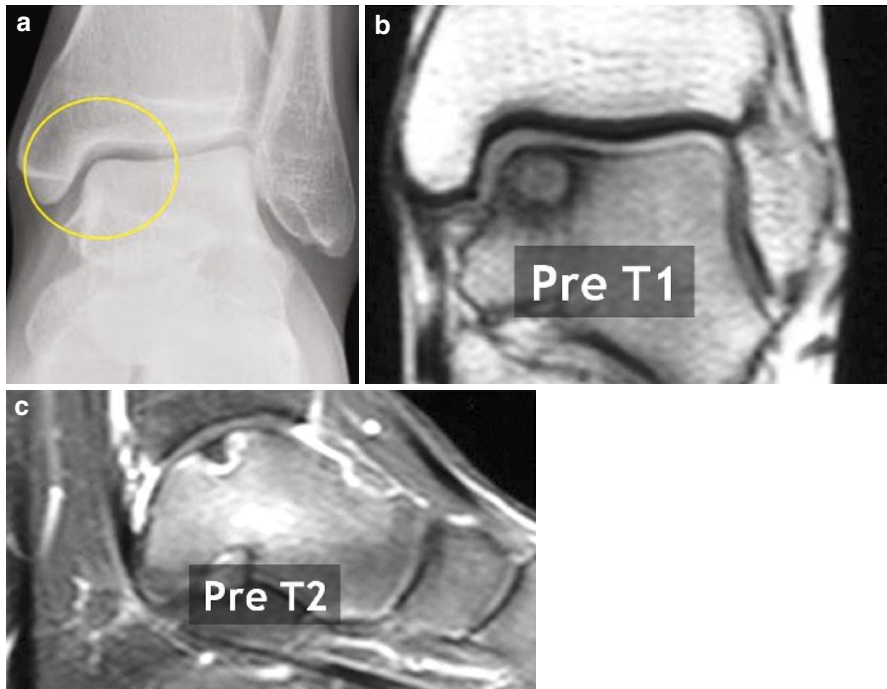


Fig. 2.1 Radiograph and MRI images of an osteochondrosis dissecans (OCD) tali at the medial talar shoulder (Berndt and Harty Stage II, Hepple and Winson stage IIa; (a), anteroposterior radiograph; (b), coronal T1 reconstruction; (c), parasagittal T2 reconstruction)^{7,21}

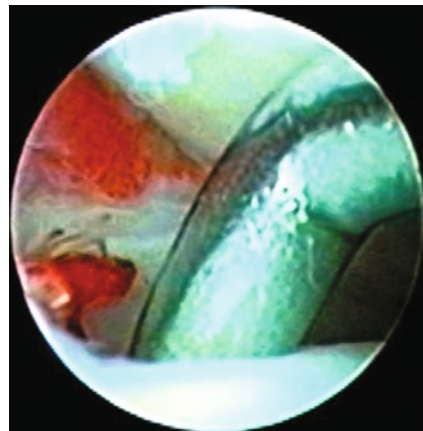


Fig. 2.2 Arthroscopic image before drilling showing intact but soft cartilage

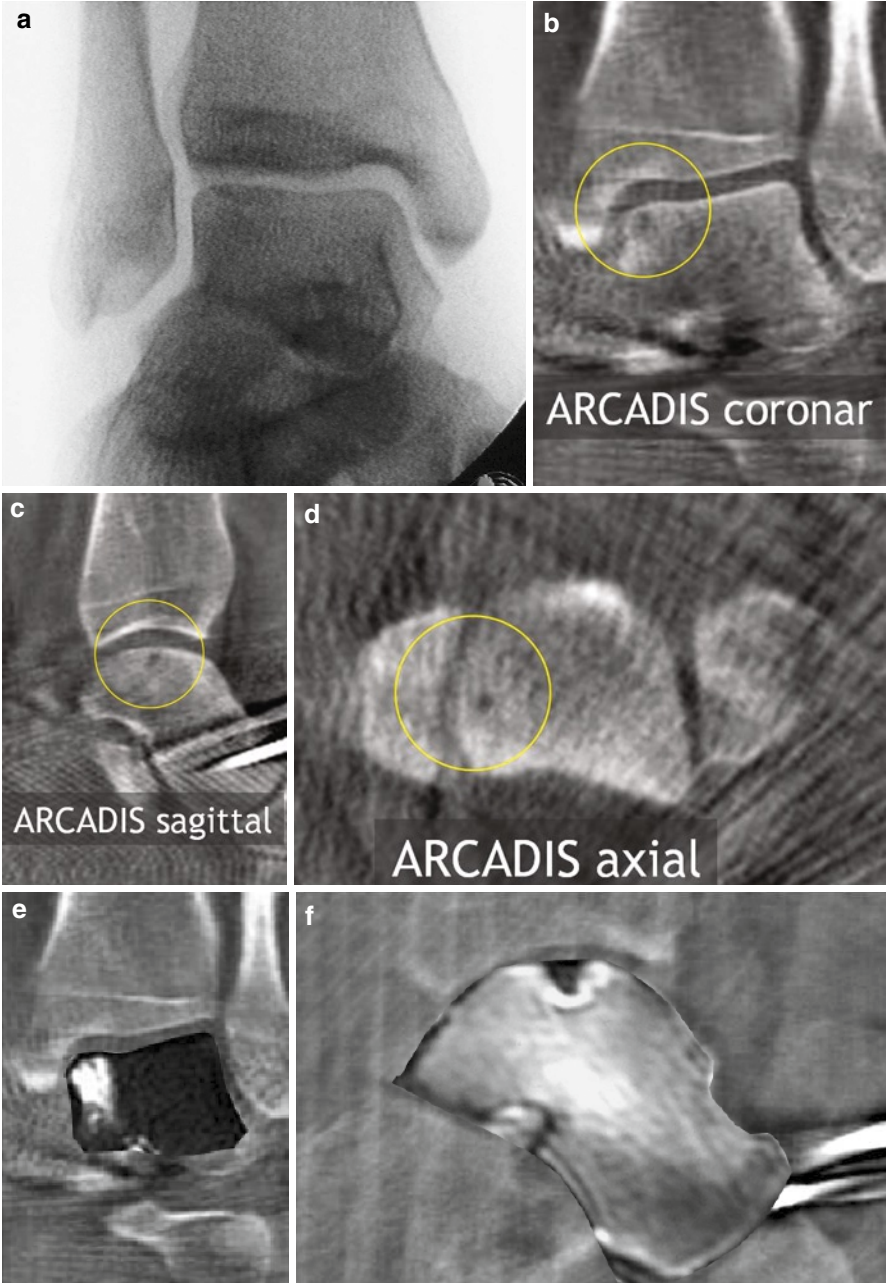
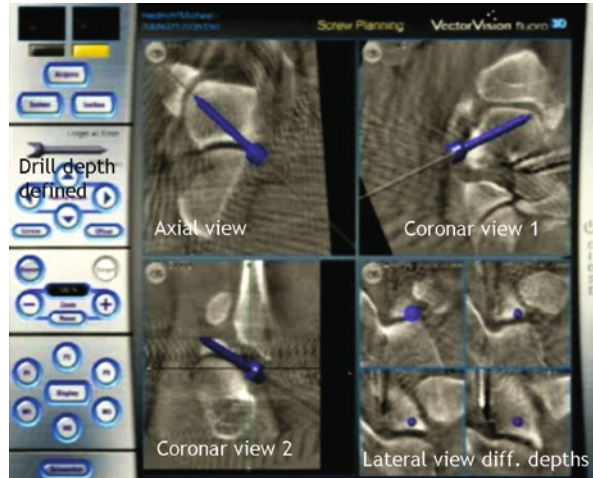


Fig. 2.3 Intraoperative image acquisition with ARCADIS-3D. (a) Shows a 2D-image without sufficient visibility of the OCD lesion. (b–d) Show the reformations of the 3D-dataset from the ARCADIS scan with good visibility of the OCD lesion. (e) and (f) show an optional image fusion of the MRI image and the ARCADIS 3D-reformation for better visualization ((e), fusion of coronal MRI T2 image of the talar body with a coronal ARCADIS 3D reformation; (f), fusion of parasagittal MRI T1 image of the talar body with a parasagittal ARCADIS 3D reformation)

Fig. 2.4 Planning of the drilling with the Vectorvision fluoro 3D software. A virtual screw with the planned length and diameter of the drill (here 4.5 mm diameter) is placed digitally by the surgeon on the screen of the CAS device



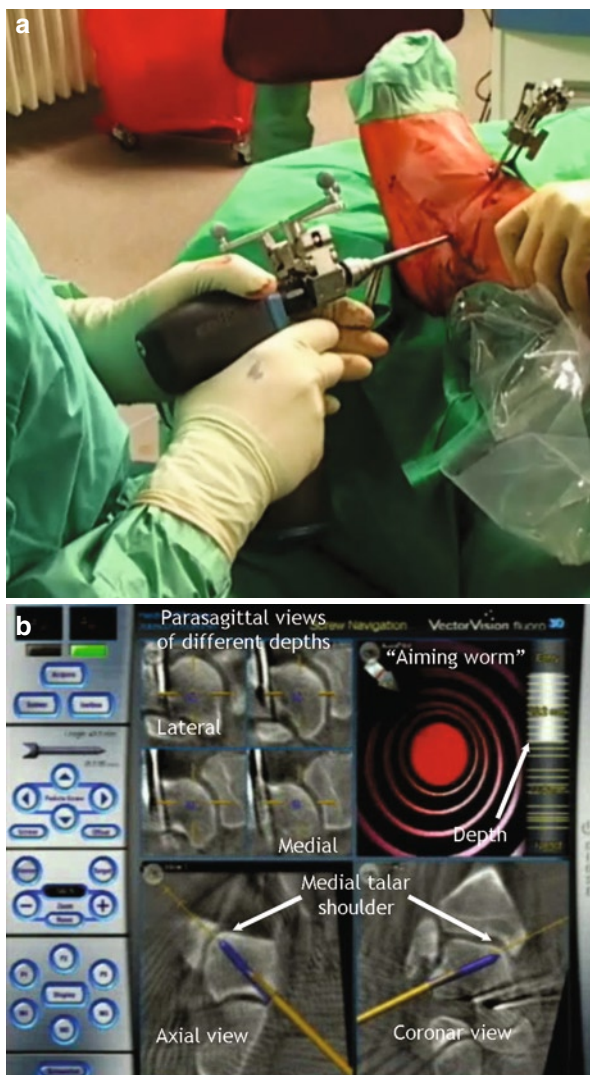
(96%), the drilling was judged to be correct at 3D imaging. In the remaining two patients (4%), the drilling ended in the caudal portion of the lesion. A perforation of the cartilage was never evident at arthroscopy. Forty-eight (92%) patients were followed up after 12 (range 6–36) months. Three patients (6%) had been received bone cartilage transplantation (OATS) due to recurrent symptoms. These patients were excluded from follow-up. At follow up, the Visual-Analogue-Scale Foot and Ankle showed a mean of 93 points (range 86–100), and the SF 36 (standardized to 100-point-maximum) showed a mean of 90 points (range 79–100).^{26,50}

2.2.3

Discussion

Several options are available for the operative management of osteochondritis dissecans stage I and II at the posterior medial talar shoulder (Berndt and Harty).^{3,19,59,62} One such option is retrograde drilling.^{3,19,59,62} An open procedure requires an extensile approach, including osteotomy of the medial malleolus.⁵⁴ Minimal invasive techniques have been developed with fluoroscopically based aiming devices.^{3,59,62} Arthroscopy-based techniques require an arthroscopically *detectable* and *reachable* lesion; this might be problematic in lesions at the postero-medial talar shoulder.^{3,59,62} To date, a thorough inspection of the entire joint is possible given the improved features of the arthroscopes (smaller diameter, better image quality). However, the identification of the exact location and size of early stage defects is still problematic, even for experienced arthroscopists with modern equipment.⁶⁰ The use of CT-based Computer Assisted Surgery (CAS) guided retrograde drilling was introduced for these patients.^{5,16,24,52} This method requires preoperative CT data that are transferred to the navigation system. Preoperative data are then synchronized with the intraoperative site in a matching process. This process of synchronization causes the main problems in CT-based CAS in the foot.^{38,43} The major issue lies in the difficult bony

Fig. 2.5 Retrograde drilling with starting point at the lateral talar process and visualization on the screen in real time. **(a)** shows the operative site, and **(b)** the screen of the CAS device with an axial view, a coronal view, four parasagittal views at different depths, the “aiming” worm, and a display for the planned and achieved depth. The “aiming” worm contains a red point and a virtual worm leading to that point. This visualization prompted the surgeon to hit the red point, which results in correct direction and length of the drilling



architecture of the foot with 28 bones and more than 30 joints. Given these anatomic conditions, the foot does not remain in the same position in the period between preoperative CT and registration. This makes the registration in the foot much more difficult than in other body regions such as the spine or the pelvis, which has bigger bones, and a lower number of bones.³⁸ Two novel CAS methods without necessary registration were designed, the C-arm based CAS and the ISO-3-D.^{38,39,43} In both, the C-arm and ISO-3-D based CAS, data are collected intraoperatively. The DRBs (Dynamic Reference Base) are fixed to the bones before the procedure, which makes matching unnecessary. Both methods combine the accuracy of the CT based CAS without the stumbling block “matching.”^{38,39,43} The C-arm based CAS provides only two-dimensional images. This is problematic for the

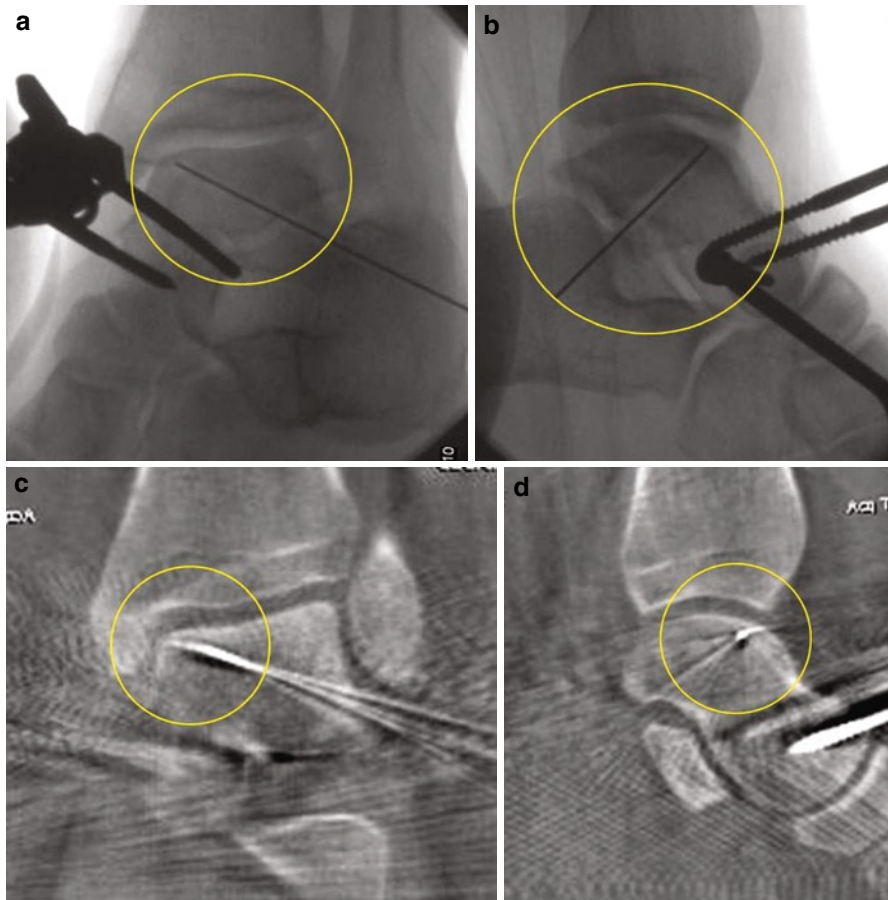


Fig. 2.6 Control of accuracy of the drilling with a second 2D- and 3D-ARCADIS scan after insertion of a Kirschner wire in the drillhole, showing the exact course of the drilling as planned preoperatively. The black areas around the Kirschner wire are artifacts, and are not equivalent to the diameter of the drilling ((a), 2D anteroposterior view; (b), 2D lateral view; (c), 3D coronal reconstruction; (d), 3D parasagittal reconstruction)

three-dimensional aiming necessary for retrograde drilling in osteochondral lesions of the talus.^{11,43} For this purpose, the ISO-3-D based CAS guided drilling is more favorable.^{11,43} In vivo and in vitro, the 3D-imaging based method is clearly superior to the 2D-imaging based method.^{11,43} However, the handling of this system was very complex. The devices were further developed for easier and faster handling less prone to error. The present ARCADIS-3D based CAS worked without problems in the patient shown. We choose a 4.5 mm drill because this was the thickest drill that was available for navigation at the time of the surgery (2004). Studies suggest that drill bit deflection interferes with the precision of the system. The precision is decreased when using small diameter and longer drill bits.²⁵ At present, we use a 5 mm drill, the thickest available for the Brainlab system.

Fig. 2.7 Arthroscopic control after drilling and autologous cancellous bone grafting, showing intact and stable cartilage surface

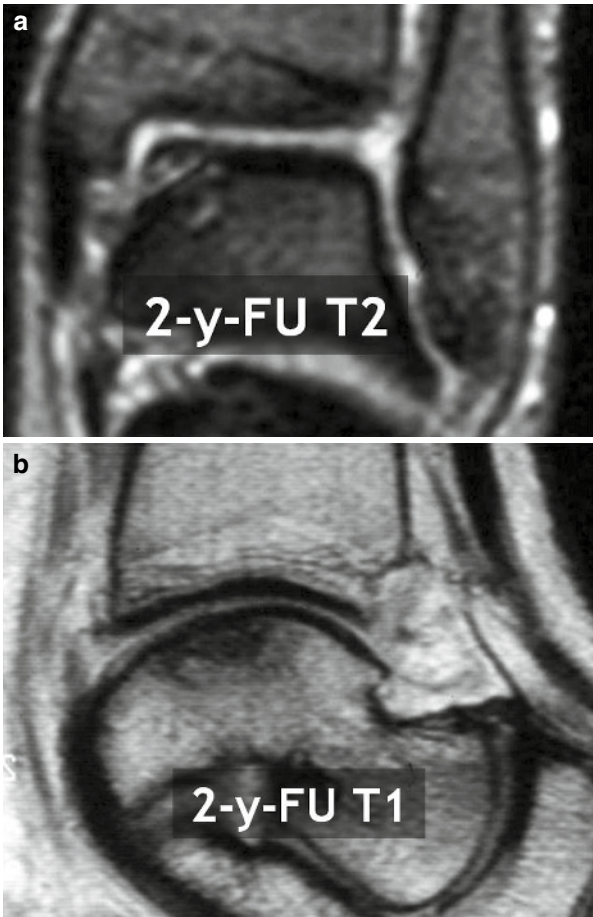
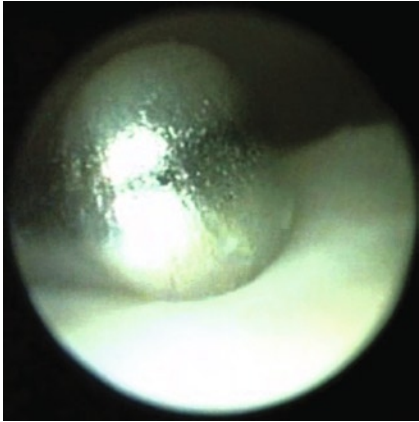


Fig. 2.8 MRI follow-up ((a), coronal reconstruction; (b), parasagittal reconstruction)

Another important issue is the device costs: these are much higher for the ARCADIS-3D based CAS (€500,000) than for arthroscopy systems. These huge device costs for the ARCADIS-3D based CAS will prevent standard use for retrograde drilling in osteochondral lesions of the talus alone despite the advantages. However, the ARCADIS-3D based CAS is also useful for other body regions such as the spine and the pelvis.^{23,31,34} Furthermore, the ARCADIS-3D alone is a valuable tool for intraoperative three-dimensional visualization.^{29,42,51} Radiation protection for patient and personnel is another important topic. The radiation of an ARCADIS-3D based CAS guided drilling procedure is higher compared with arthroscopically based drilling. However, the ARCADIS-3D based CAS procedures produce less radiation than all conventional C-arm based procedures and CT based CAS.¹⁷

In conclusion, the advantages of this technique are real time intraoperative three-dimensional imaging for the use of navigation without the need for anatomical registration (matching) and an immediate intraoperative control of surgical management. Accuracy is confirmed with immediate intraoperative three-dimensional imaging. Our results indicate that ARCADIS-3D based Computer Assisted Surgery (CAS) guided retrograde drilling is a good alternative to arthroscopically guided or 2D-imaging based CAS guided drilling of OCD lesions of the talus

2.3

Part 2: CAS Guided Correction Arthrodeses at Foot and Ankle

Ankle, hindfoot and midfoot deformities are common.^{1,4,8,20,22,33,37,45,57,67,68} The biomechanical consequences of these deformities frequently lead to clinical symptoms like pain and gait disturbances.^{2,12,28,33,35,53,55,56,63,66,67} Corrective osteotomy and joint fusion (arthrodesis) is useful for these peri-articular deformities.^{32,33,37,55,64,67} The correction of the deformities is challenging, since nonunion and remaining deformity with symptoms is frequent.^{32,33,37,55,64,67} Preoperative planning of a correction is standard, and during the operative procedure the goal is to achieve the planned correction.^{32,33,37,55,64,67} Preoperative imaging with radiographs and computer tomography (CT) allows accurate planning of the correction, and accuracy is enhanced using computerized planning systems.¹³ However, during the procedure the realization of the planned correction is difficult, as the correction process is performed without guidance by a conventional C-arm.^{32,33,37,39,64,67} In other fields of orthopedic surgery such as spine, hip and knee surgery, Computer Assisted Surgery (CAS) is helpful and more accurate than the conventional methods without navigation.^{9,10,14,18,27,30,36,40,44,58,65} For the foot, a system for C-arm based CAS guided correction was developed, since CT-based CAS did not work successfully in experimental settings.³⁸ This system showed then sufficient feasibility and accuracy in the first clinical cases.^{39,41} The method is in routine use in the author's institution. The first 118 cases were analyzed regarding how CAS affected the time spent, the accuracy of the procedure, and what problems occurred with the use of the CAS in each case.

2.3.1

Methods

2.3.1.1

Devices

Two different navigation systems with wireless Dynamic Reference Bases (DRB) were used (Models VectorVision and Navivision, Brainlab Inc., Kirchheim-Heimstetten, Germany). Before September 1, 2006, a VectorVision system with VectorVision Trauma software (Brainlab Inc., Kirchheim-Heimstetten, Germany) was used. The system was connected with a modified C-arm (Model Exposcope, Instrumentarium Imaging Ziehm Inc., Nuernberg, Germany). The accuracy of the correction was checked with intraoperative three-dimensional imaging with ISO-C-3D (Siemens Medical Inc., Munich, Germany). ISO-C-3 is a motorized mobile C-arm that provides fluoroscopic images during a 190° orbital rotation, resulting in a 119 mm data cube.⁴² Multiplanar and two-dimensional reconstructions can be obtained from these 3D data sets.⁴²

From September 1, 2006, a Navivision with VectorVision Trauma software (Brainlab Inc., Kirchheim-Heimstetten, Germany) was used. This system was built in an ARCADIS-3D (Siemens Medical Inc. Germany), which is a further development from the ISO-C-3D (Siemens Medical Inc., Munich, Germany). The accuracy of the correction was checked with ARCADIS-3D with a comparable function such as ISO-C-3D (see paragraph ‘Evaluation’).

The two navigation systems were not compared since the functions including the software was identical. The principal difference was the hardware: the Navivision is built in the ARCADIS-3D, whereas the Vectorvision is not built in the ISO-C-3D.

2.3.1.2

CAS-Procedure

One DRB was fixed to each of the two bones or fragments that had been planned for correction in relation to each other (Fig. 2.9).⁴⁷ Calibration images, anteroposterior and lateral digital radiographic images were obtained (Figs. 2.10a–c).⁴⁷ Before September 1, 2006, a modified C-arm was used and the data was transferred to the navigation device. From September 1, 2006, the images were obtained with the ARCADIS-3D without data transfer, since the navigation system is built in the ARCADIS-3D. A verification process with a DRB-equipped pointer followed (Fig. 2.11).⁴⁷ The correction was then planned and performed. For the planning, a manual selection of the bone for navigation and a definition of the bone axis were performed. This step was performed by the surgeon using the sterile draped touch screen of the navigation system (Fig. 2.12).⁴⁷ During the correction, the angle motion and translational motion between the bones or fragments in all degrees of freedom were displayed on the screen of the navigation system (Fig. 2.13).⁴⁷ Furthermore, virtual radiographs with the moving bones or fragments were displayed on the screen (Fig. 2.14).⁴⁷ The C-arm/ARCADIS-3D was not used during the correction process. After correction,

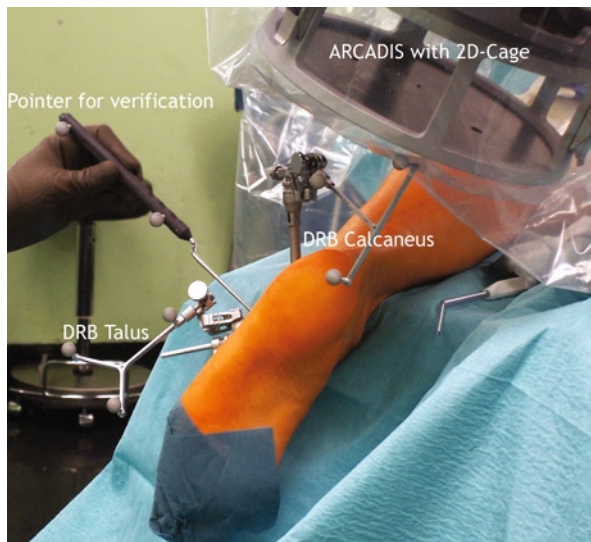


Fig. 2.9 Correction arthrodesis of the subtalar joint. The patient is prone position, and a posterolateral approach was used. Two autologous tricortical bone blocks and autologous cancellous bone was obtained from the posterior pelvic rim. Two 7.3 mm cancellous screws with short threads (Synthes, Umkirch, Germany) were inserted. The image shows the DRBs fixed to talus and calcaneus the ARCADIS-3D with 2D-navigation cage. The pointer for verification later used for verification is shown (see Fig. 2.11)

retention was performed with 2.0 mm Kirschner wires. Internal fixation with screws, plates or intramedullary nails followed. For ankle or subtalar fusions, the drillings for the screws were CAS guided (Fig. 2.14a–c).⁴⁷ For the combined ankle and subtalar fusions, the guide wire for the nail reamer was inserted with CAS guidance. The accuracy of the correction and implant position was then checked with intraoperative three-dimensional imaging with ISO-C-3D/ARCADIS-3D (Figs. 2.15 a and b).

The times for the different CAS steps were measured with a stopwatch by a medical student or student nurse who attended the cases. The time for preparation was measured with the starting point when the first DRB fixation was started and the endpoint when the current values for angles and translation were displayed on the screen of the CAS device. The period includes fixation of the two DRBs, 2D-image acquisition, verification of the accuracy with the DRB-equipped pointer, definition of the two bones including the bone axes, and reading of the current angles and values on the screen of the CAS device. The time of the correction process was measured with the starting point when the surgeon started to move the bones for the definite correction, and the endpoint when this correction process was ended and before the correction was fixed with Kirschner wires (see above). This time period did not include the additional surgical maneuvers described below.

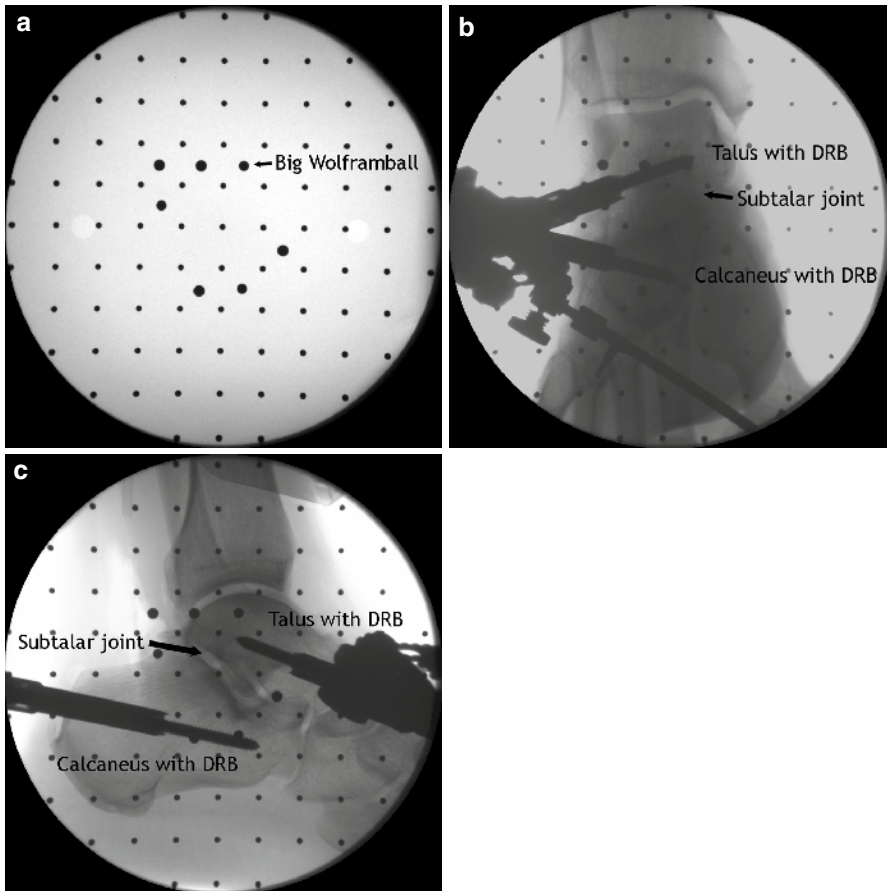


Fig. 2.10 Same patient as Fig. 2.9. 2D-Image Acquisition. First, an empty image showing the all seven large Wolfram balls of the 2D-navigation cage is acquired (**a**). This allows later exact placement of the foot, regardless of the visibility of the seven large Wolfram balls. This is a very important step, since the navigation system needs at least five clearly visible large Wolfram balls for exact verification. This is typically not the case when the foot with the DRBs is correctly placed for the anteroposterior (**b**) and the lateral (**c**) views

2.3.1.3

Additional Surgical Maneuvers

No external distraction devices for correction means were used. No osteotomies with CAS guidance were performed. After the two bones were equipped with DRBs, the remaining articular cartilage was removed. The bones were moved with CAS guidance in relation to each other until the planned position was achieved. Osteotomies were performed only in the tarsometatarsal joint of the first ray to achieve sufficient area of bone contact at the fusion site. In none of the patients hindfoot osteotomies were performed to achieve the

Fig. 2.11 Same patient as in Figs. 2.9 and 2.10.

Verification with the Pointer. The pointer is placed at the base of the proximal DRB (see Fig. 2.9). This position is exactly shown on the screen which proves an exact verification

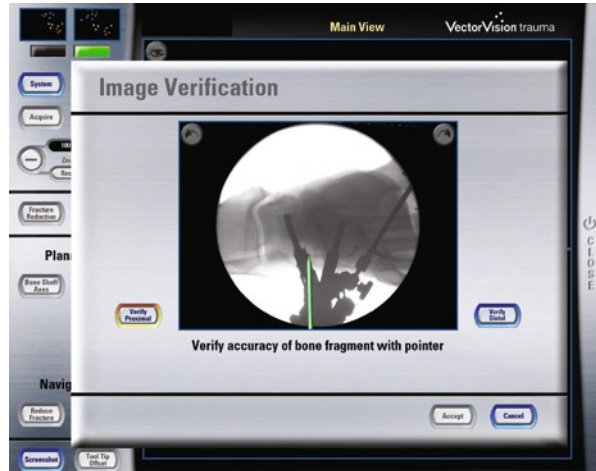


Fig. 2.12 Same patient as in Figs. 2.9–2.11. This is the definition of the bone axis of the talus and calcaneus, and the definition of the bones by outlining them digitally on the sterile draped touchscreen. These steps have to be performed before the bone position is altered, for example by opening the joint and removing the remaining cartilage



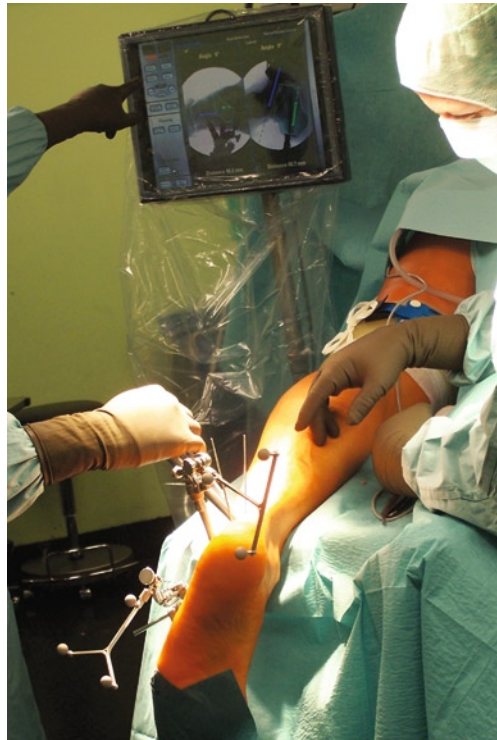
planned position. However, soft tissue releases were frequently performed in patients operated without CAS.^{32,33,37,55,64,67} After the correct positions of the bone were achieved, the remaining gaps or defects were filled with cancellous bone and/or tricortical bone blocks from the pelvic rim.

2.3.1.4

Study Setting

A clinical study was performed in a university hospital level I trauma center before September 1, 2006, and in a university teaching hospital level II trauma center from September 1, 2006. The surgical staff involved in the study consisted of qualified and experienced orthopedic trauma surgeons, interns, residents, and fellows. The surgical

Fig. 2.13 Same patient as in Figs. 2.9–2.12. CAS guided correction of calcaneus in relation to the talus. Both bones, the angles and translations between the bones are shown in an anteroposterior and lateral virtual fluoroscopic view on the screen in real time. Real fluoroscopy is not needed during this correction process. Insertion of the bone grafts and later transfixation of the subtalar joint with two 2.0 mm Kirschner wires is performed under permanent monitoring of the angles and translations



procedures were exclusively performed by the first author. The assessment of the deformity and the planning was performed on the basis of the clinical finding, radiographs with full bearing and computer tomography (CT). Pathological angles and translation, for example a talocalcaneal angle, were identified on the standing radiographs and CT, and the amount of correction was defined. The preoperative angles or translations, the planned correction, and the amount of correction was then drawn with lines, angles and translations on the corresponding CT images using a terminal and software of the institutional Picture Archiving Communication System (PACS). These images served as the baseline for the planned correction.

2.3.1.5

Results

One hundred and eighteen patients were included (correction arthrodeses at ankle, $n = 24$; subtalar joint, $n = 28$; ankle and subtalar joint, $n = 19$; midfoot/tarsometatarsal (TMT) joint, $n = 28$, others, $n = 19$). The average time needed for preparation was 5 min and 45 s (4–30 min), and the correction process took 27 s (12–240). The CAS system encountered

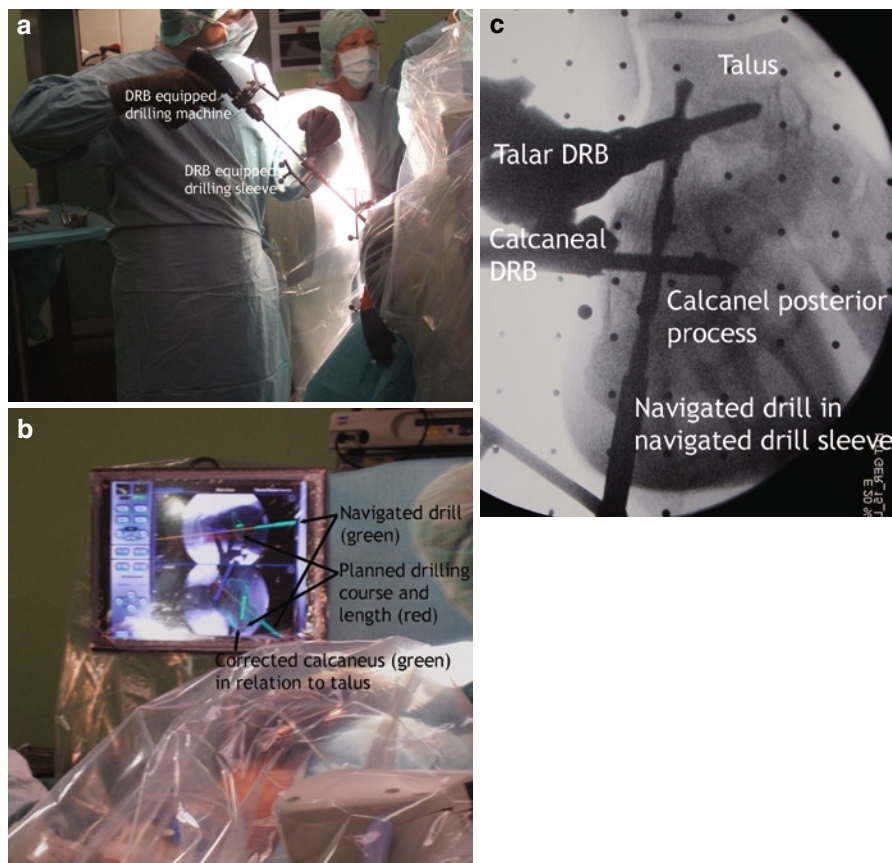


Fig. 2.14 Same case as Figs. 2.9–2.13. CAS guided drilling with a 5.0 mm drill with a navigated drilling machine and a navigated drill sleeve was used (a). In (b), the real time view of the planned drilling direction is shown, including depth (red), and the actual drilling direction including depth (green). The images with the altered/corrected position of the calcaneus are used, not the images with the earlier position of the calcaneus, and not the images of the actual calcaneus position. (c) Shows a fluoroscopic image obtained during the first drilling

malfunctions in four procedures (3%) in which the verification process was not successful, i.e., the system did not consider the bones in the correct position. In the remaining cases, all the achieved angles/translations were within a maximum deviation of 2°/mm when compared to the planned correction ($p < 0.05$).

One hundred and two (86%) patients completed follow-up after 9.2 (6–36) months. In all cases fusion, was registered. The scores were AOFAS 82 (46–100, maximum possible hindfoot score for ankle fusion 92, subtalar fusion 94, ankle and subtalar fusion 86), Visual-Analogue-Scale Foot and Ankle 79 (43–100).

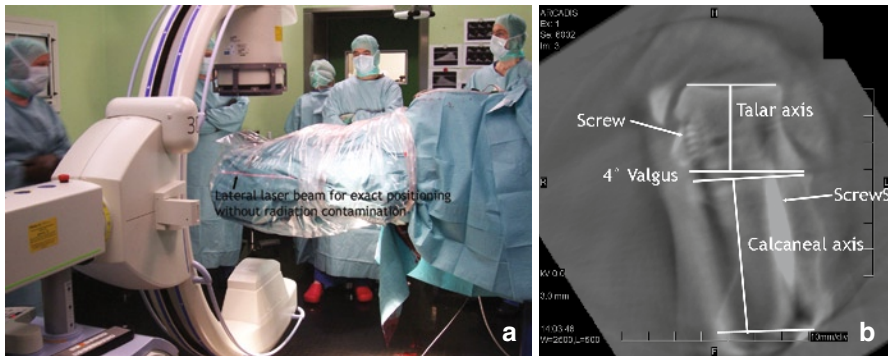


Fig. 2.15 Same patient as in Figs. 2.9–2.14. Three-dimensional intraoperative imaging with ARCADIS-3D for analysis of implant and bone position after screw fixation is complete. The table with the legs is totally draped with a sterile plastic bag and the ARCADIS-3D is placed with laser aiming devices for correct anteroposterior and lateral positing without radiation contamination (**a**). The entire staff leaves the area with radiation contamination before the scan. (**b**) Shows the analysis on a paracoronal reconstruction through the posterior facet with measurement of the achieved axis between talus and calcaneus. Here, 4° of valgisation in the frontal/coronal plane was planned and achieved. No other abnormality was observed and considered for correction, including, for example, talo-calcaneal axis, talo-metatarsal-1-axis in the dorsoplantar view and the lateral view, congruity of the talo-navicular-joint, and calcaneal inclination/pitch angle

2.3.1.6

Discussion

The CAS guided correction showed great accuracy. Despite pre-operative planning, correction is sometimes limited by soft tissues and other restraints.^{33,37,55,64,67} Still, the surgeon involved in this study was always able to achieve the pre-operative planning goals intraoperatively. Some of the complex deformities involved in this study had bony abnormalities which were not correctable with the CAS system, and not exactly measureable with the ISO-C-3D/ARCADIS-3D system (e.g., widening of the lateral wall of the calcaneus). These components of the deformities were assessed, but they were not measured with a pre-operative CT. After the correction, they were assessed with an intraoperative ISO-C-3D/ARCADIS-3D scan (data not shown). A measurement of these components, for example the widening of the lateral wall of the calcaneus, has not been performed in any other study to our knowledge. We are aware of the problems in measuring angles on images.^{15,33,37,41,56,64} To avoid these problems, we measured the angles and translations digitally on the computer that was involved in obtaining the images, either pre-operative CT or intraoperative ISO-C-3D/ARCADIS-3D. The accuracy of the correction achieved was measured by a co-investigator, who was not involved in the planning and the surgical procedures, with images that were obtained intraoperatively, and a re-evaluation of the “remaining” accuracy at a later stage is in process. In the follow-up until now, we have observed the similar problems as in cases without CAS. During the study, we have especially observed a loss of correction. For example, in one patient necessitating subtalar

arthrodeses with correction of a decreased talocalcaneal angle in the lateral radiographs, the data at a 3 months follow-up differed in comparison with the intraoperative measurement taken (data not shown).

The time spent was less in cases, mostly more than 10 min spent for preparation. The correction process itself was very fast, especially regarding the problems with the conventional C-arm based correction.^{33,41} In our experience, the correction without CAS guidance needs more time because the necessary frequent C-arm checks.⁶¹ However, no data from other groups are available about the time spent of in correction process in comparable cases.

We could not isolate data from the literature regarding measurements of the difference between the pre-operatively planned versus the achieved corrected angles and translations with conventional correction or without.^{15,33,37,56,64} Even in previous data from conventional arthrodeses of the subtalar joint, we could not determine the difference, as the planned correction was not recorded.⁶¹ Rammelt et al. indirectly reported a difference between the planned and the achieved correction in correction arthrodeses of the subtalar joint.³⁷ They described that the measurements of the unaffected side were used as a template for the planning of the correction.³⁷ These measurements, i.e., the planned corrections, were achieved 38.5–61.8% of the times for the different measurements.³⁷ In our study, the planned correction was achieved on an average of 75–100% (mean, 95.0%), of the time for all types of correction arthrodeses, and 87.5–100% (mean, 98.6%) of the time for correction arthrodeses of the subtalar joint. Regarding the higher percentages in our study, a sufficient comparison of the conventional correction without CAS and CAS guided correction in one single randomized controlled study is available. We observed that, in patients with a higher amount of planned correction, the deviation of the achieved correction in percent from the planned correction is higher than in patients with small amounts of planned correction.

Based on our results, CAS is helpful in complex three-dimensional corrections, and in drillings.^{38,39,41} The clinical relevance of CAS-based methods might be high in those cases, because the improved accuracy may lead to an improved clinical outcome, i.e., complex corrections in ankle, hind- and midfoot deformities.^{2,6,12,28,33,35,53,56,63,66,67}

In conclusion, C-arm based CAS guided correction of posttraumatic deformities of the ankle and hindfoot provides a very high accuracy and a fast correction process.⁴¹ The clinical relevance of these methods is high in these patients, as high accuracy may lead to an optimized clinical outcome.^{2,6,12,28,33,35,53,56,63,66,67} Further studies, including clinical outcome assessment, will show whether patients will benefit from the high accuracy provided with this method.

For the future, the integration of the different computerized systems will improve the handling and clinical feasibility. An integration of pre-operative pedography, planning software, CAS, ISO-C-3D/ARCADIS-3D and Intraoperative Pedography (IP) in one Integrated Computer System for Operative Procedures (ICOP) will be favorable.³⁹ Within this type of ICOP, pre-operative computerized planning will include pre-operative radiographic, CT, MRI and pedography data. Pre-operative computerized planning results will be transferred to the CAS device. The CAS-system will be guided by biomechanical assessment with IP that allows not only morphological, but also biomechanical based CAS. The intraoperative three-dimensional imaging (ISO-C-3D/ARCADIS-3D) data and the IP-data will be matched with the data from the planning software to allow immediate improvements of reduction, correction and or drilling/implant position in the same procedure.³⁹

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