Integration of Computer-Based Systems in Foot and Ankle Surgery

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Introduction

Foot and ankle surgery at the end of the 20th century was characterized by the use of sophisticated computerized preoperative and postoperative diagnostic and planning procedures [1, 9]. However, intra-operative computerized tools that assist the surgeon during his or her struggle for the planned optimal operative result are missing. This results in an intra-operative »black box« without optimal visualization, guidance and biomechanical assessment [9]. The future will be characterized by breaking up this intra-operative »black box«. We will have more intra-operative tools to achieve the planned result [9]. Intra-operative three-dimensional imaging (ISO-C-3D), Computer Assisted Surgery (CAS) and Intra-operative Pedography (IP) are three possible innovations to realize the planned procedure intra-operatively [9]. These devices might be especially helpful for minimally invasive surgery.

These novel methods are in clinical use at our institution for further development. This chapter especially analyzes the feasibility and potential clinical benefit of navigation for foot and ankle surgery. Since the intra-operative three-dimensional imaging (ISO-C-3D) and intra-operative pedography (IP) are two other innovations that are closely connected to navigation, these two methods are also described.

Intra-Operative Three-Dimensional Imaging (ISO-C-3D)

In foot and ankle trauma care, mal-position of extraosseous or intra-articular screws and gaps or steps in joint lines frequently remain undiscovered when using intra-operative fluoroscopy, and are only recognized on postoperative computed tomography (CT) scans [3]. Earlier preclinical studies showed that evaluation of reduction and implant position with a new C-arm based three-dimensional imaging device (ISO-C-3D) is better than with plain films or C-arm alone and comparable to CT scans [3].

Study Results

A prospective consecutive clinical study was performed in a level one trauma center [9]. The hypothesis was that the ISO-C-3D could detect failures of reduction or implant position that had not been detected with a conventional C-arm in a considerable percentage.

Patients with foot and ankle trauma or reconstruction surgery that were treated in the Trauma Department of the Hannover Medical School between July 1, 2003 and June 30, 2005 were considered for inclusion in the study. Before the use of the device, the reduction and implant position had to judged to be correct by the surgeon using a conventional C-arm. The patients were either placed on a special metal-free carbon table or on a standard table. Time spent, changes after use of the ISO-C-3D and surgeons' ratings (visual analogue scale, VAS, 0–10 points) were recorded. The surgeons' ratings for image quality for the carbon table and the standard table were compared (t-test, significance level 0.05). The surgeons' ratings for image quality for the carbon table and the standard table were compared (t-test, significance level 0.05).

101 patients/cases (no bilateral ISO-C-3D use) were included (Fractures: pilon, n=15; Weber-C ankles, n=12;

isolated dorsal Volkmann, n=3; talus, n=7; calcaneus, n=32; navicular, n=2; cuboid, n=2; Lisfranc-fracture-dislocation, n=8; ankle/hindfoot arthrodesis with or without correction, n=4/16). Carbon table was use in 80 (79%) cases and a standard table in 21 (21%). The operation was interrupted for 430 seconds on average (range, 300–700); 100 seconds on average for preparation, 120 seconds on average for the ISO-C-3D-scan and 210 seconds on average for evaluation of the images by the surgeon. In 39% (39 of 101) of the cases, the reduction (n=16, 16%) and/or implant position (n=30, 30%) was corrected after ISO-C-3D-scan during the same procedure. The ratings of the eight surgeons involved were 9.2 (5.2–10) for feasibility, 9.5 (6.1–10) for accuracy and 8.2 (4.5–10) for clinical benefit. The image quality was rated 9.1 (8.0–10) for the carbon tables, and 8.7 (7.0–10) for the standard tables (difference rating carbon table versus standard table, t-test, $p>0.05$). The image quality was rated 9.1 (8.0–10) for the carbon tables, and 8.7 (7.0–10) for the standard tables (difference rating carbon table versus standard table, t-test, n.s.). Figure 63.1 shows a clinical example.

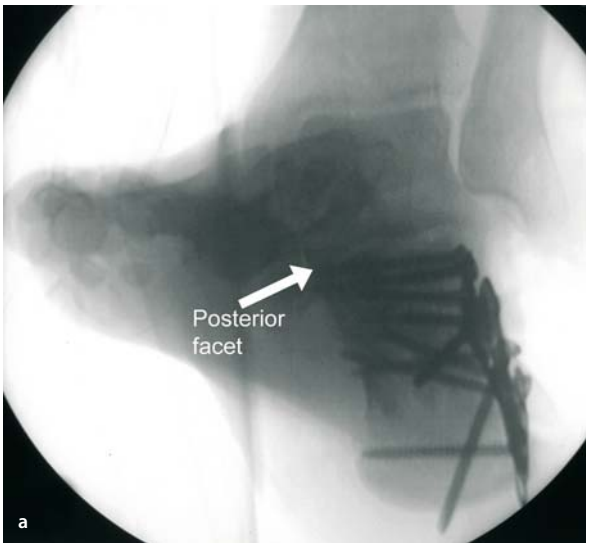
In this study, in almost 40% of cases, reduction and/or implant position was corrected after ISO-C-3D-scan at the same procedure. The radiation contamination is comparable to a standard CT scan and corresponds to 39 seconds fluoroscopy time with a modern digital C-arm. The image quality with a carbon table is not better than with a standard table. Consequently, the use of a carbon table is not necessary for ISO-C-3D-scan at the foot region.

In conclusion, the intra-operative three-dimensional visualization with the ISO-C-3D can provide important information in foot and ankle trauma care that cannot be obtained from plain films or C-arm alone [12]. The use is not considerably time consuming. The ISO-C-3D is extremely useful in evaluating reduction and/or implant position intra-operatively and can replace a postoperative CT scan.

Computer-Assisted Surgery (CAS)

CT-Based CAS

The accuracy of the reduction in hind- and midfoot fractures and fracture-dislocations correlates with the clinical result [14, 20]. The same is true for the correction of hind- and midfoot [16, 17, 19]. However, an accurate correction or reduction with the conventional C-arm based procedure is challenging [19]. CT-based Computer Assisted Surgery (CAS) has become a valuable tool for the correction and reduction in other body regions [2, 5, 6]. Especially a more exact reduction could be achieved [5–7].



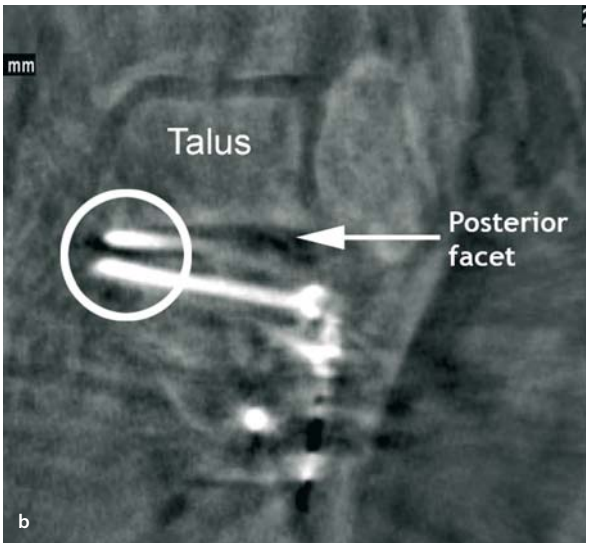


Fig. 63.1a,b. Intra-operative three-dimensional imaging (ISO-C-3D). Calcaneus fracture after open reduction and internal fixation with plate and screws. After evaluation with C-arm including Broden´s view (**a**), a correct reduction and implant position was confirmed by the surgeon. The ISO-C-3D-scan showed a screw penetrating the posterior facet medially (**b**), and the screw position was corrected during the same procedure

CT-based CAS may also be useful for the correction of hind- and midfoot deformities and for the reduction in hind- or midfoot fractures and fracture-dislocations.

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Study Results

The purpose of an experimental study at our institution was to compare CT based CAS assisted correction of hind- and midfoot deformities with C-arm based correction [8].

Sawbone™ (Pacific Research Laboratories, Vashon, WA, USA) specimen models »Large Left Foot/Ankle«, »Large Left Foot/Ankle With Equinus Deformity«, »Large Left Foot/Ankle With Calcaneus Malunion«, »Large Left Foot/Ankle With Equinovarus Deformity« were used. A CT-scan of each deformity specimen model (n=3) was performed. The goal of the correction was to transform the shape of the pathology specimen models into the shape of the normal specimen model. Two methods were used for the correction, a, conventional C-arm based correction, and, b, CAS (CT based, Surgigate™, Medivision, Oberdorf, Switzerland & Northern Digital Inc., Waterloo, Ontario, Canada) based correction. Five specimens of each deformity model were corrected with each method. The surgeon's direct view to the specimens was disabled by drapes. During the correction procedure, the visualization of the specimen was exclusively provided by the image of the C-arm or the CAS device. Retention was performed with 1.8 mm titanium K-wires.

The shape was graded normal in all specimens (n=15) in the CAS group, and in eight of the specimens in the C-arm group (other grades in C-arm group: nearly normal, n=6, abnormal, n=1, Chi^2-test, p=0.05). The time needed for the procedure was longer in the CAS group, and the fluoroscopy time was shorter in the CAS group than in the C-arm group (mean values and range shown, t-test utilized):

- time entire procedure, CAS, 782 (450–1020) s, C-arm, 410 (210–600) s, p<0.001;
- fluoroscopy time, CAS, 0s, C-arm, 11 (8–19) s, p<0.001.

The measurement *differences* between the corrected specimens and the normal specimen model were as follows (mean values and standard deviation shown, t-test utilized): foot length, CAS, -1.7 +/– 1.9 mm, C-arm, –4.1 +/– 3.8 mm, p=0.03; length of longitudinal arch, CAS, –0.9 +/– 0.9 mm, C-arm, –5.6 +/– 4.9 mm, p=0.001; height of longitudinal arch, CAS, –0.1 +/– 0.5 mm, C-arm, 1.7 +/– 4.3 mm, p=0.14; calcaneus inclination, CAS, 0.1 +/– 1.4°, C-arm, 2.7 +/– 4.8°, p=0.05; calcaneus length, CAS, –0.5 +/– 0.4 mm, C-arm, –2.8 +/– 1.3 mm, p=0.005; Boehler's angle, CAS, 0.4 +/– 1.1°, C-arm, 4.1 +/– 8.6°, p=0.37.

In conclusion, in an experimental setting, CT based CAS provided higher accuracy for the correction of hind- and midfoot deformities than C-arm based correction [8].

The reasons for the double time needed with CT-based CAS in comparison with the C-arm based method are the requirements of the data transfer of the DICOM-data of the pre-operative CT scan to the CAS device and especially the very time consuming matching process during the registration procedure. The main problems with the matching are based on the difficult bony architecture of the foot with 28 bones and more than 30 joints. Due to these anatomic conditions, the foot does not regularly maintain its complete integrity and position during the pre-operative CT and the registration. This makes the registration in the foot much more difficult than in other body regions like the spine or the pelvis with lesser and bigger bones and joints [2, 5, 6]. Fortunately, during this experimental study was planned and performed, two CAS methods without registration were intended: the C-arm based CAS and the ISO-3-D based CAS. These CAS methods without registration are especially interesting for the foot region.

ISO-C-3D-Based CAS

In our institution ISO-C-3D based CAS was co-developed and firstly used for retrograde drillings in osteochondral defects of the talus [9]. CT-based Computer Assisted Surgery (CAS) guided retrograde drilling of osteochondral lesions had been previously described with promising results as a new technique [4]. In addition to the current method of arthroscopic evaluation and treatment and CT based CAS, we also introduce an alternative technique of using lSO-C-3D based CAS guided retrograde drilling of the lesion.

Study Results

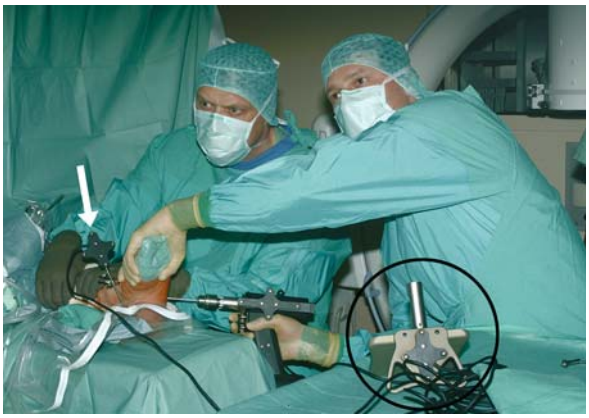
All patients with symptomatic osteochondrosis dissecans stadium I and II according to Berndt and Harty of the talus between June 1st, 2003 and July 31st were included in a follow-up study (Fig. 63.2a). The patients were treated with ISO-C-3D based navigated retrograde drilling. Time spent, accuracy, problems, surgeons' rating (Vi-

sual Analogue Scale [VAS], 0–10 points) were recorded and analyzed. The accuracy of the drillings were assessed by the intra-operative three-dimensional imaging device (ISO-C-3D™) Follow-up were performed clinical and radiological using following scores: Visual Analogue Scale Foot and Ankle (VAS FA) and SF 36 (standardized on a possible 100 point maximum for better comparison with the VAS FA).

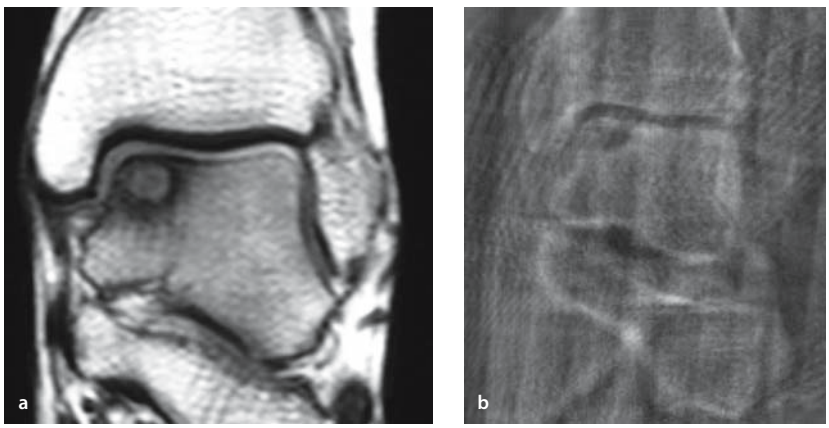
Technical Background. An ISO-C-3D description above, see ◘ Fig. 63.1) was connected to a navigation system (Surgigate™, Medivision, Oberdorf, Switzerland & Northern Digital Inc., Waterloo, Ontario, Canada). After fixation of a Dynamic Reference Basis (DRB) to the bone, an ISO-C-3D scan follows (◘ Fig. 63.2b). The data are transferred to the navigation system. The starting- and end-point, direction and length of the drilling is planned on the screen of the navigation system using the standard software. A trajectory for the following drilling is placed in the virtual bone on the screen. The drilling is performed with a modified navigated electrical power drilling machine (Powerdrive™, Synthes Inc., Bochum, Germany, ◘ Fig. 63.3). The direction and length of the drilling is shown on the monitor of the navigation device. Standard fluoroscopy is not needed during the entire procedure.

Ten patients (n=6 at lateral talar shoulder; n=4 at medial talar shoulder) were treated with ISO-C 3D based CAS guided retrograde drilling. Time needed for preparation, including the placement of the DRB, scanning time and preparation of the trajectories was 580 s (500–750). All drillings were in correct position (deviation from planned position less than 2° and 2 mm). No surgery related complication, especially no infection occurs. The surgeons' ratings were: feasibility, VAS 9 (7.3–10); accuracy 8.5 (5.8–10); clinical benefit 8.5 (5.7–10). Time of follow-up was 18 (12–28) month. Nine patients could be included in the follow-up study. One patient required OATS after initial clinical improvement. This patient had to be excluded. The VAS FA was 92 (86–98), the SF 36 89 (79–97). The different score categories averaged as follows:

- Pain: VAS FA 85 (69–100), SF36 87 (80–100);
- Function: VAS FA 94 (88–99), SF36 96 (83–100);
- Other complains: VAS FA 96 (87–99), SF36 85 (67–93).



◘ **Fig. 63.3.** ISO-C-3D-based Computer Assisted Surgery (CAS). ISO-C-3D-based CAS guided retrograde drilling in osteochondrosis dissecans tali. Retrograde drilling with starting point at the lateral talar process and visualization on the screen of the CAS device in real time [*white arrow*, Dynamic Reference Base (DRB) fixed to the talar neck through a stab incision; black arrow, drilling machine equipped with DRB; circle, device for drill calibration]



◘ **Fig. 63.2a,b.** ISO-C-3D-based Computer Assisted Surgery (CAS). ISO-C-3D-based CAS guided retrograde drilling in osteochondrosis dissecans tali. MRI image (**a**) and ISO-C-3D image from data transferred to navigation system (**b**) of an osteochondrosis dissecans tali (Berndt & Harty stadium II)

The introduced system was reliable and in frequent use at our department for surgical procedures in different body regions. The advantages of the introduced technique are an actual and almost real-time intra-operative three-dimensional imaging for the use of navigation without the need for anatomical registration and an immediate intra-operative control of surgical treatment [9]. Our results reveal that ISO-C-3D-based Computer Assisted Surgery (CAS) guided retrograde drilling is an alternative to arthroscopically guided or open drilling for osteochondral lesions of the talus. To date we use the same ISO-C-3D but a different navigation device which is easier to use (VectorVision™, BrainLAB Inc., Kirchheim-Heimstetten, Germany; description see below). The tremendous device costs for the ISO-C-3D based CAS will prevent standard use for retrograde drilling in osteochondral lesions of the talus alone despite the advantages. However, the ISO-C-3D based CAS is also useful for other body regions like spine and pelvis (see other chapters). Furthermore, the ISO-C-3D alone is a valuable tool for intra-operative three-dimensional visualization as described above.

C-arm Based CAS

As described above CAS is considered to be useful for the correction of hind- and midfoot deformities and for the reduction in hind- or midfoot fractures and fracture-dislocations [8]. CT based CAS provided high accuracy in an experimental setting but the very cumbersome obligatory registration process prevented the clinical use [8]. A registration free C-arm based CAS guided correction was fortunately developed and studied at our institution.

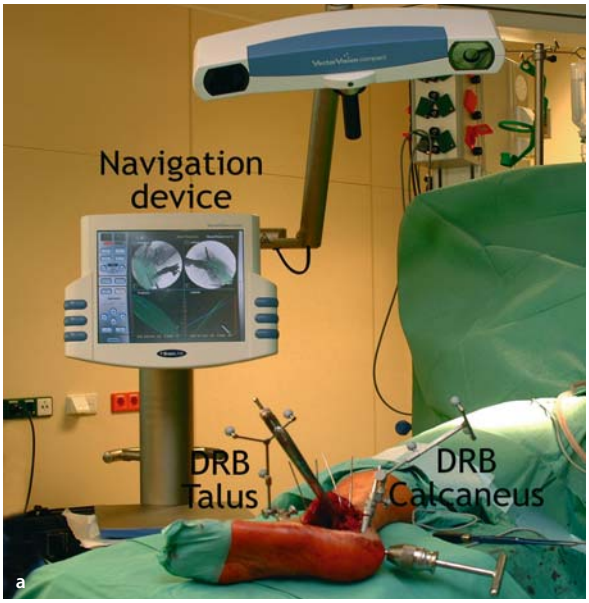
Study Results

Patients with posttraumatic deformities of the ankle or subtalar joint with deformity (mal-alignment) were included in a prospective clinical follow-up study. C-arm based CAS guided arthrodeses with correction of the deformity were performed. Time spent, accuracy, problems, surgeons' rating (Visual Analogue Scale [VAS], 0–10 points) and follow-up (Visual-Analogue-Scale Foot and Ankle (VAS FA), American Orthopaedic Foot and Ankle Society Hindfoot Score (AOFAS), SF36) were analyzed. The accuracy of the corrections was assessed by a new C-arm based three-dimensional imaging device (ISO-C-3D).

Technical Background. A navigation system with wireless Dynamic Reference Bases (DRB) was used (VectorVision™, BrainLAB Inc., Kirchheim-Heimstetten, Germany). The system was connected with a modified C-arm (Exposcope™, Instrumentarium Imaging Ziehm Inc., Nuernberg, Germany, ◘ Fig. 63.4a). One DRB was fixed to each of the two bones or fragments that had been planned for correction in relation to each other. With the C-arm, anteroposterior and lateral digital radiographic images were obtained, and the data were transferred to the navigation device. Then the correction was performed. 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. 63.4b). Furthermore, virtual radiographs with the moving bones or fragments were displayed on the screen. C-arm use was not used during the correction process. After correction, retention was performed with 2.0 mm K-wires. Then the accuracy of the correction was checked with C-arm and intra-operative three-dimensional imaging with ISO-C-3D (Siemens Inc., Germany). Finally screw fixation followed. The insertion of the screws was also C-arm based CAS guided (data not shown).

12 patients were included (ankle correction arthrodesis, n=3; subtalar correction arthrodesis, n=6; combined ankle/subtalar joint correction arthrodesis, n=2; Lisfranc correction arthrodesis, n=1). Time needed for preparation, scanning time and preparation on the screen for the correction was 500 s (400 – 900). The correction process took 45 s (30–60). All planned angles and translations were exactly achieved as planned before (deviation from planned correction less than ±2° for angles or ±2 mm for translations). Three surgeons were involved. Feasibility, VAS 9.5 (9–10); accuracy 9.8 (9.5–10); clinical benefit 9 (8–10). 10 (83%) patients completed follow-up after 14 (6–27) months. All arthrodeses were fused at follow-up. The corrected angles and translations at follow-up (analyzed on radiographs) did not differ significantly from those measured intra-operatively (see above; t-test, $p>.05$). The VAS FA averaged 47 (25–81), the AOFAS Hindfoot Score 57 (40–64), and the SF36 54 (34–80). The different score categories averaged as follows: pain: VAS FA 47 (14–85), SF36 46 (11–93); function: VAS FA 41 (14–85), SF36 45 (8–85); other complaints: VAS FA 52 (19–83), SF36 70 (55–84).

The feasibility of the introduced method was favorable. The time spent is less than 10 minutes for preparation. The correction process is very fast and extreme accurate, especially regarding the problems with the conventional



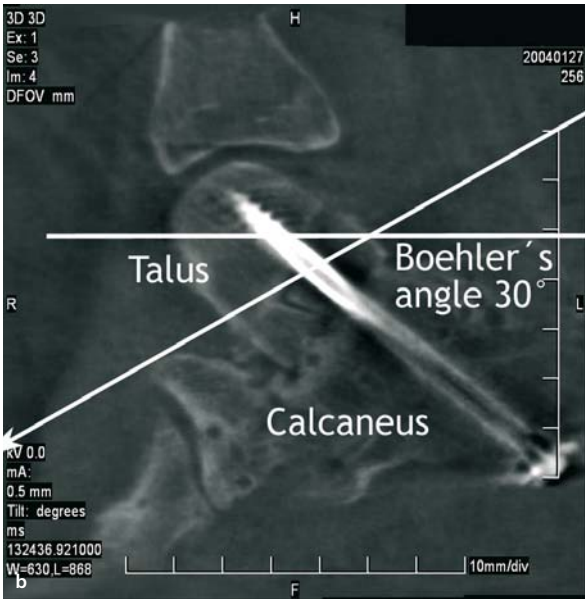


Fig. 63.4a,b. C-arm based Computer Assisted Surgery (CAS). C-arm based CAS guided correction of hindfoot deformity after mal-united calcaneus fracture. Fixation of a wireless Dynamic Reference Base (DRB) to the talar neck and the tuber calcanei. Image acquisition with a modified digital C-arm (**a**). Antero-posterior and lateral digital radiographic images were obtained, and the data were transferred to the navigation device. 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 (**b**). Furthermore, virtual radiographs with the moving bones or fragments were displayed on the screen

C-arm based correction. In our experience, the correction without CAS guidance needs more time because the necessary frequent C-arm controlling. Furthermore, it is much more difficult, not only because of the difficult visualization but also because the very demanding correction process with three-dimensional motion of two different fragments in relation to each other.

In conclusion C-arm based CAS guided correction of posttraumatic deformities of the ankle and hindfoot region is feasible and provides very high accuracy and a faster correction process [11]. The significance of the introduced method is high in those cases, because the improved accuracy may lead to an improved clinical outcome [16, 17, 19].

Intraoperative Pedography (IP)

For any kind of reduction or correction at the foot and ankle an immediate biomechanical assessment of the reduction result would be desirable [16, 17, 19]. This is especially true for a CAS-guided reduction or correction, that is supposed to be more accurate than a conventional reduction [13]. The reduction or correction control is normally performed with a C-arm or an ISO-C-3D if available [8, 12]. Analyzing the position of the bones radiographically allows conclusions about the biomechanics of the foot [19]. However, pedography is considered to be more effective for the analysis of the biomechanics of the foot [15]. So far, pedography for biomechanical assessment was only available during clinical follow-up [9]. An intra-operative pedography (IP) would be useful for immediate intraoperative biomechanical assessment [9].

Study Results

A new device was developed to perform IP. A feasibility study was first performed. Then a study for validation followed to compare introduced method with standard dynamic pedography [10]. Finally, a prospective consecutive

randomized multi-center study is in progress to analyze the clinical benefit of IP

For an intra-operative introduction of standardized forces to the foot sole, a device named Kraftsimulator Intraoperative Pedographie (KIOP, manufactured by the Workshop of the Hannover Medical School, Hannover, Germany; Registered Design No. 20 2004 007 755.8 by the German Patent Office, Munich, Germany) was developed (Fig. 63.5). The pedographic measurement is performed with a custom-made mat with capacitive sensors (PLIANCE™, Novel Inc., Munich, Germany). The system allows real-time pedography and comparison to the contra-lateral side. The measurements were performed in neutral ankle position. In this neutral ankle position, the influence of the missing muscle action in the anaesthetized patient is considered to be minimal since the EMG in awake standing individuals with comparable ankle position is silent [18].

Validation Study. The validation was performed in two steps:

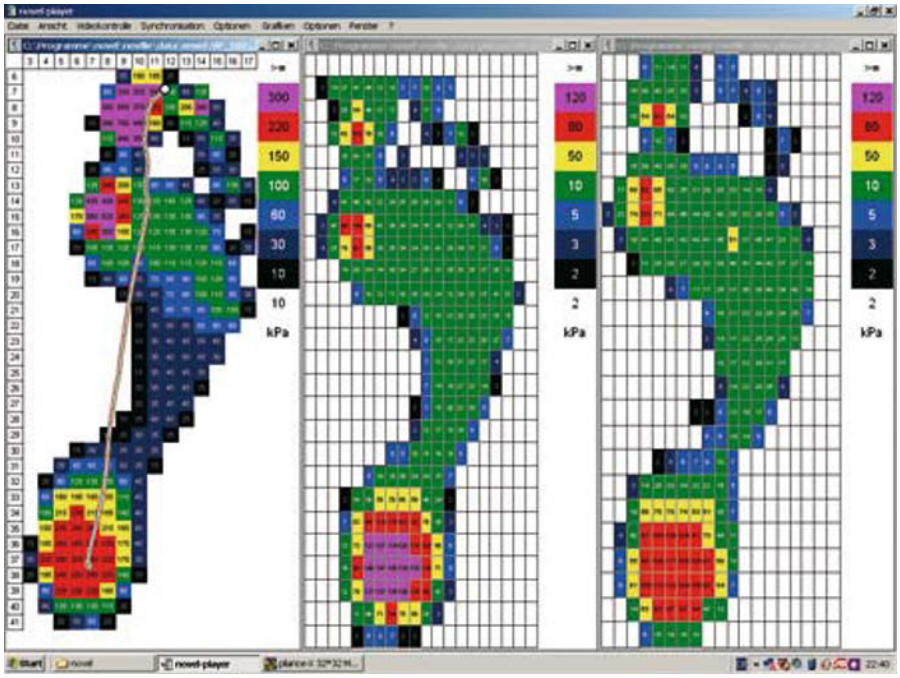
- Step 1: Comparison of standard dynamic pedography (three trials, walking, third step, three trials, mid stance force pattern), static in standing position (three trials) and pedography with KIOP in healthy volunteers (three trials, total force 400 N). For dynamic pedography and pedography in standing position, a standard platform (EMED™, Novel Inc., Munich, Germany) was used.
- Step 2: Comparison of pedography in standing position, pedography with KIOP in non-anaesthetized and anaesthetized patients (three trials, total force 400 N). Patients with operative procedures performed at the knee or distal to the knee were excluded. Only patients with general or spinal anesthesia were included.

Additionally, a qualitative analysis was performed for both steps (Fig. 63.6). The analysis was focused on the force distribution and not on the force values. The relation of the forces of different regions as hindfoot, midfoot, forefoot (1st metatarsal, 2nd-4th metatarsal, 5th metatarsal), and medial versus lateral were compared. The different measurement and qualitative analyses were compared (t-test, Oneway ANOVA).

The results of the validation process were as follows.

Step 1: 30 individuals were included (age, 26.1±8.6 years; gender, male: female = 24: 6). Step 2: 30 individuals

Fig. 63.5a,b. Intra-operative Pedography (IP). The newly developed device for intra-operative force introduction (Kraftsimulator Intraoperative Pedographie® (KIOP®), registered design no. 202004007755.8, German Patent Institute, Munich, Germany & St. Paul, MN, USA, **a**). The custom made mat for force registration (pliance®, Novel, Munich, Germany & St. Paul, MN, USA) is covered intra-operatively with a sterile plastic bag and is placed on the KIOP® as also shown in Fig. 64.4. The size of the mat is 16×32 cm. The mat includes 32×32 sensors with a sensor size of 0.5×1 cm. **b** A scheme of the modus for intra-operative pedography (IP)



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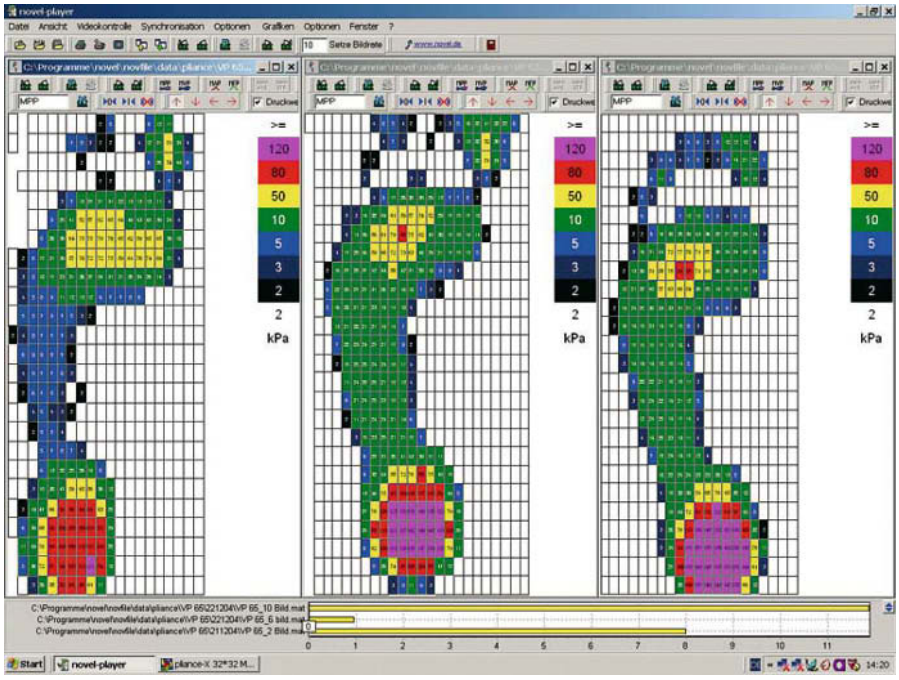

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Fig. 63.6a,b. Intra-operative pedography (IP). Images from the qualitative analysis of the validation process of IP. **a** Step 1; awake volunteer; *left*, pedography with KIOP; *middle*, static pedography in standing position; *right*, standard dynamic pedography. For dynamic pedography and pedography in standing position, a standard platform (EMED™, Novel Inc., Munich, Germany) was used. **b** Step 2; non-anesthetized/anesthetized patient; *left*, pedography in standing position; *middle*, pedography with KIOP in non-anaesthetized individual; *right*, IP in anesthetized individual

were included (age, 55.3±30.3 years; gender, male: female = 24: 6). No statistical significant differences were found in both steps between the methods, and between the methods of step 1 and 2 (t-test & ANOVA, p>0.05).

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Clinical Prospective Study. Sixteen patients were included until March 15, 2006 (ankle correction arthrodesis, n=2; subtalar joint correction arthrodesis, n=4; correction arthrodesis midfoot, n=4, correction forefoot, 4; Lisfranc-fracture-dislocation). Nine patients were randomized for the use of intra-operative pedography, whereas four had no intra-operative measurement. The mean preoperative scores were as follows: AOFAS: 51.6±22.6; VAS FA: 45.2±14.4; SF36: 47.3±21.4. No score differences between the two groups occurred (t-test, p>0.05). The mean interruption of operative procedure for the intra-operative pedography was 323±32 seconds. In four of the nine patients (44%) changes were made after intra-operative pedography during the same operative procedure (correction modified, n=3; screw tightened, n=1). The follow-up has not been completed so far.

In conclusion, IP is feasible and valid since no statistical significant differences were found between the measurements of the introduced method for IP in anaesthetized individuals and the standard dynamic and static pedography. In the future dynamic IP with registration of the entire foot sole is planned for an even more sophisticated biomechanical assessment [10]. During the clinical use, in 50% of the cases a modification of the surgical correction were made after intra-operative pedography in the same surgical procedure. A follow-up of these patients has to be completed to show if these changes improve the clinical outcome. In any case, IP was be able to detect Insufficient biomechanical behavior of the foot and may lead to modifications in the same procedure, and not after pedography in the office weeks or months later [10].

What Do We Need When?

The perfect surgeon who does not make any mistakes without any guidance does not need any of the introduced systems. However, the surgical staff involved in foot and ankle surgery consists of experienced surgeons as well as interns, residents and fellows in training. In times of increasing legal pressure regarding working hours, the acquisition of surgical experience is harder. Tools for improved intra-operative imaging (ISO-C-3D), guidance (CAS) or biomechanical assessment (IP) may help the surgeon in training to achieve the planned result with less experience [9].

ISO-C-3D [12]

The ISO-C-3D is most helpful in closed procedures and/or when axial reformations provide information that is not possible to obtain with a C-arm or with direct visualization. Weber-C fractures and calcaneus fractures are examples for these special situations. The ISO-C-3D is less helpful when easy visualization with a C-arm or under direct vision is possible as for example in Weber-B fractures during open reduction and internal fixation.

Computer-Assisted Surgery (CAS) [8, 11, 13]

CAS is helpful in complex three-dimensional corrections or reduction, and in closed placement of drillings and/or screw positioning [8]. The significance of the introduced CAS-methods is high in those cases, because the improved accuracy may lead to an improved clinical outcome like complex corrections in the hind- and midfoot deformities [16, 17, 19]. CAS is too complex and time consuming for all those cases that are accurately and easily performed by the experienced surgeon.

Intra-Operative Pedography (IP) [10]

IP will be useful for all those cases in which biomechanical assessment may lead to an immediate improvement of the achieved surgical result [9]. The same cases that are analyzed with clinical pre- or postoperative pedography so far, will potentially profit from IP. The surgeons experience is also crucial for the use of IP, since experienced surgeons who do not use pedography in their office, may not use it intra-operatively also. IP as introduced was made possible by the newly developed device for intra-operative force introduction (Kraftsimulator Intraoperative Pedographie (KIOP), registered design no. 202004007755.8, German Patent Institute, Munich, Germany).

Integrated Computer System for Operative Procedures (ICOP)

For the future, the integration of the different computerized systems will improve the handling and clinical feasibility. An integration of preoperative pedography, planning software, CAS, ISO-C-3D and IP in one Integrated Computer System for Operative Procedures (ICOP) will be favorable. Within this kind of ICOP, the preoperative computerized planning will be able to include preoperative radiographic, CT, MRI and pedography data. The preoperative computerized planning result will be transferred to the CAS device. An intra-operative two-dimensional (C-arm) or three-dimensional (ISO-C-3D) imaging will allow registration-free CAS and will be matched with preoperative CT and or MRI images. The CAS-system will be guided by biomechanical assessment with IP that allows not only morphological but also biomechanical based CAS. The intra-operative three-dimensional imaging (ISO-C-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 [9].

In conclusion, in the future computerized methods for improved intra-operative imaging, guidance and biomechanical assessment will help to realize the planned operative result [9].

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