Experimental Comparison Between Computer Assisted Surgery (CAS) Based and C-Arm Based Correction of Hind- and Midfoot Deformities

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Abstract

This experimental study compares the accuracy of Computer Assisted Surgery (CAS) based correction of hind- and midfoot deformities, and C-arm based correction. Five specimens of three different deformity models (Sawbone™) were corrected with each method and the results were compared. The specimen visualization during correction was exclusively provided by the C-arm or CAS screen.

The shape was graded normal in all corrected specimens (n = 15) in the CAS group, and in eight of the specimens in the C-arm group (Chi^2-test, p = 0.05). Parameters (t-test utilized): time entire procedure, CAS, 782 (450–1020) s, C-arm, 410 (210–600) s, p < 0.001; fluoroscopy time, CAS, 0 s, C-arm, 11 (8–19) s, p < 0.001; measurement differences between corrected specimens and normal specimen model: foot length, CAS, –1.7 ± 1.9 mm, C-arm, –4.1 ± 3.8 mm, p = 0.03; length longitudinal arch, CAS, –0.9 ± 0.9 mm, C-arm, –5.6 ± 4.9 mm, p = 0.001; height 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; Böhler's angle, CAS, 0.4 ± 1.1°, C-arm, 4.1 ± 8.6°, p = 0.37.

CAS promises to be a valuable tool for higher accuracy for correction or reduction in the hind- or midfoot region. Clinical studies must show if this higher accuracy can be achieved in real operations also, and if this leads to better clinical results.

Key words

Correction · deformity · midfoot · hindfoot · fluoroscopy · navigation system

Introduction

The accuracy of the reduction in hind- and midfoot fractures and fracture-dislocations correlates with the clinical result [1, 3, 8, 17, 19, 35, 41, 49, 50]. The same is true for the accuracy of the correction of hind- and midfoot deformities [2, 10, 26, 29, 32, 36, 40, 45, 47, 49]. However, an accurate correction or reduction with the conventional C-arm based procedure is challenging [4, 46, 49]. Computer assisted surgery (CAS) has become a valuable tool for the correction and reduction in other body regions [5, 9, 11 – 16, 18, 20 – 25, 27, 28, 30, 31, 33, 34, 39, 43, 44, 48]. Especially a more exact reduction could be achieved [5, 7, 11, 20 – 22, 25, 27, 28, 31, 34, 37, 38, 42, 44]. CAS may also be useful for the correction of hind- and midfoot deformities and for the reduction of hind- and midfoot fractures and fractures dislocations, although it has not been used in the foot region so far [6].

This experimental study compares the handling and accuracy of CAS based correction of hind- and midfoot deformities in artificial bone specimens with C-arm based correction. The purpose of this study is to find out if CAS is more accurate than the conventional C-arm based method, and if the handling is adequate for clinical use. The aim is then to use CAS for reduction or correction in the hind- and midfoot.

Methods

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 (Fig. **1**). A CT scan of each deformity specimen model (n = 3) was performed to enable CAS. The goal of the correction

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Bibliography

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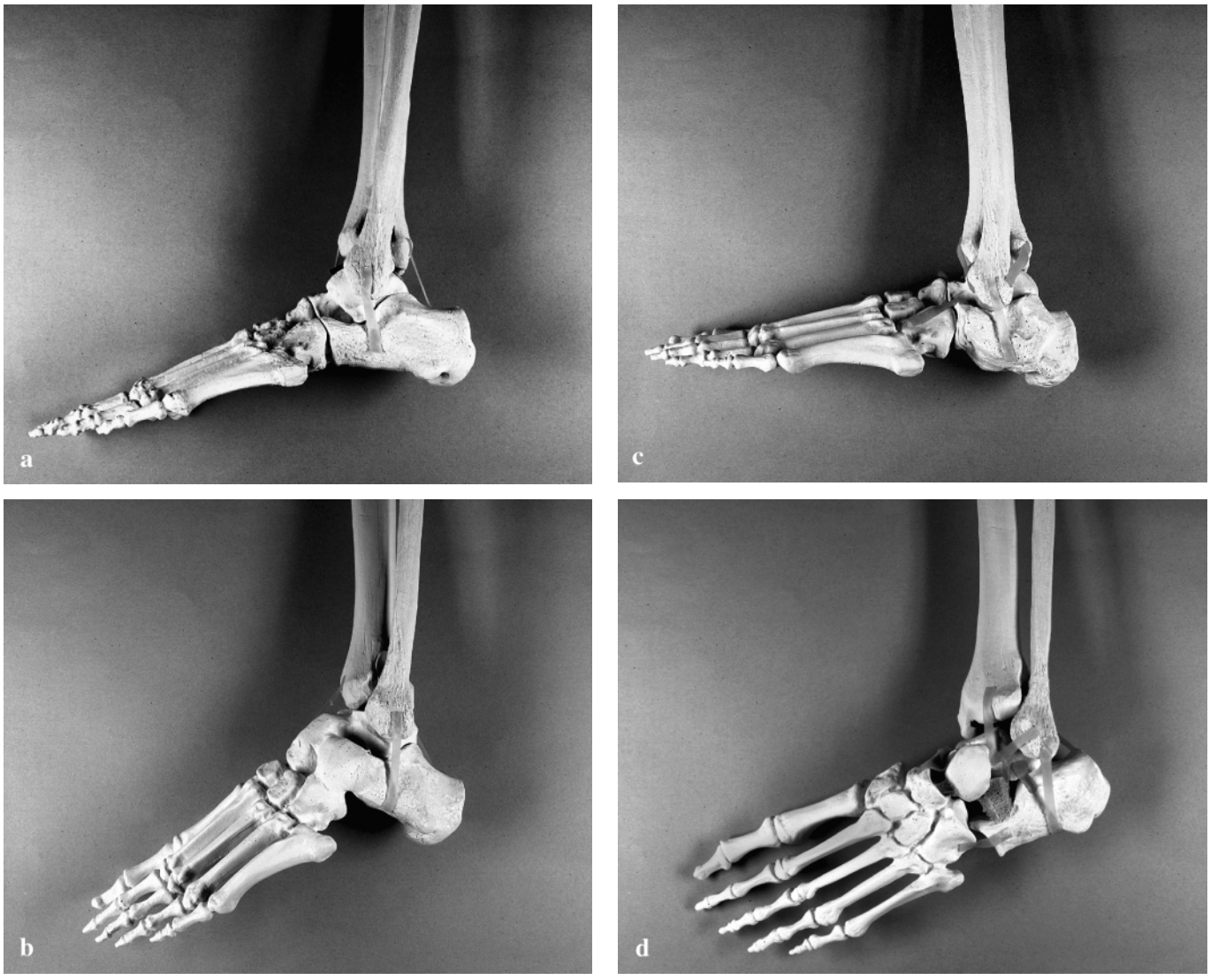

Fig. **1** Sawbone™ (Pacific Research Laboratories, Vashon, WA, USA) specimen models "Large Left Foot/Ankle" (**a**), "Large Left Foot/Ankle with Equinus Deformity" (**b**), "Large Left Foot/Ankle with Calcaneus Malunion" (**c**), "Large Left Foot/Ankle with Equinovarus Deformity" (**d**).

was to transform the shape of the pathology specimen models (Fig. **1 b–d**) into the shape of the normal specimen model (Fig. **1 a**). 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 (Figs. **2** and **3**). Five specimens of each deformity model were corrected with each method. Standardized osteotomies were performed before the correction when necessary (in models with equinovarus [Fig. **4**] and calcaneus malunion [Fig. **5**]). The surgeon's direct view to the specimens was disabled by drapes (Figs. **2** and **3**). During the correction procedure, the visualization of the specimen was exclusively provided by the image of the C-arm or the CAS device (Figs. **2** and **3**). Retention was performed with 1.8 mm titanium K-wires (Fig. **5**). The CAS procedure included data transfer of the DICOM (Digital Imaging and Communications in Medicine) data from the CT device to the CAS device. Then, planning of the correction with the PAO™ software module (Surgigate™, Medivision, Oberdorf, Switzerland & Northern Digital Inc., Waterloo, Ontario, Canada) was performed with the imported data. During this planning procedure, the cuts of the standardized osteotomies were also virtually performed with the software, and the two resulting fragments were considered for the correction process. Each fragment was then equipped with a marker (DRB™, Synthes, Bochum, Germany, Medivision, Oberdorf, Switzerland) at the following location: models "Equinus Deformity" and "Equinovarus Deformity" at tibia shaft and shaft of metatarsal I, and model "Calcaneus Malunion" at tuber and anterior process of the calcaneus. The markers were fixed with an external fixation device (Minifixateur™, Synthes, Bochum, Germany) to two 4.0 mm Schanz screws (Synthes, Bochum, Germany) that were inserted in the specimens at the described positions. A standard surface mapping of the specimen followed (Surgigate™, Medivision, Oberdorf, Switzerland). Finally, the correction was performed so that the fragments virtually reached the position that was specified during the planning procedure.

The following parameters were registered: time needed for entire procedure and for reduction process, fluoroscopy time, foot length, length and height of longitudinal arch, calcaneus inclination, hindfoot angle for all models (n = 30) and additionally Böhler's angle, calcaneus length for the "Calcaneus Malunion" speci-

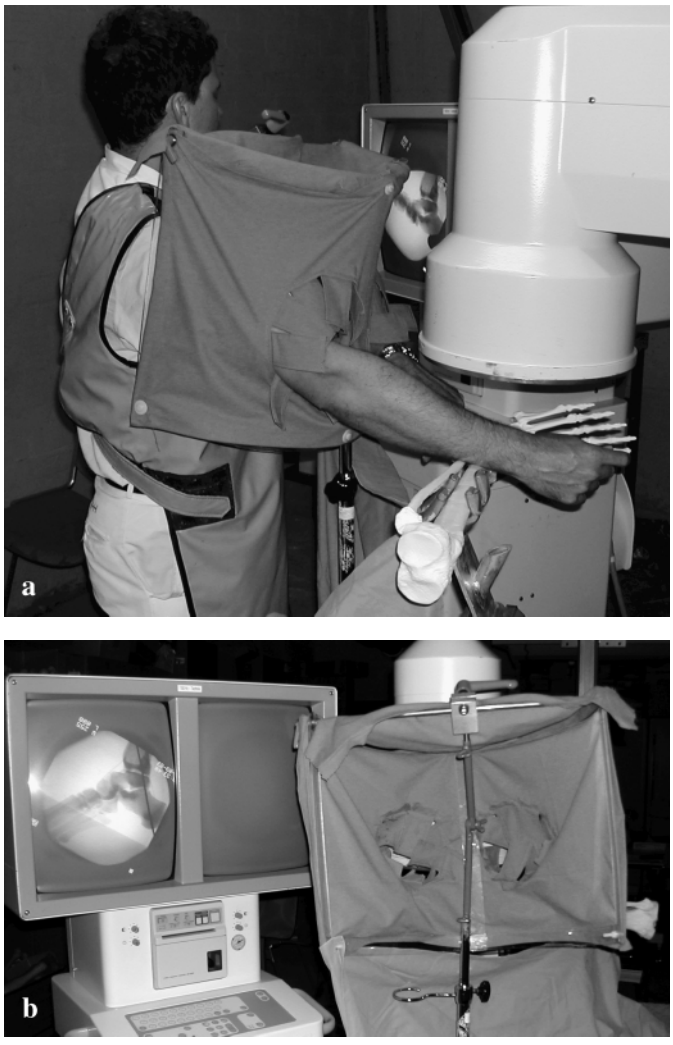

Fig. 2 Setting of C-arm based correction (**a**). **b** shows the surgeon's view during the procedure.

Fig. **3** Setting of CAS based correction (**a**). **b** shows the surgeon's view during the procedure.

men models (n = 10). The measurements were performed using standardized landmarks (Fig. **6**). The length and height measurements were performed with an electronic gauge (Absolute Digimatic™, Mitutoyo Inc. Germany, Neuss, Germany), the hindfoot angle was measured with a goniometer (Inklinometer™, Zebris, Tuebingen, Germany), and the Boehler's angle was measured with a ruler (Geodreieck™ gross, Pelikan, Hannover, Germany) on standard lateral radiographs. The shape of the corrected specimens was graded in normal, nearly normal, abnormal, or severely abnormal. The parameters of the two correction method groups (CAS vs. C-arm) were statistically compared (t-, Chi^2-tests).

According to the specimen measurements, the differences between the corrected specimen models and the normal specimen model were also compared.

Results

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 entire procedure

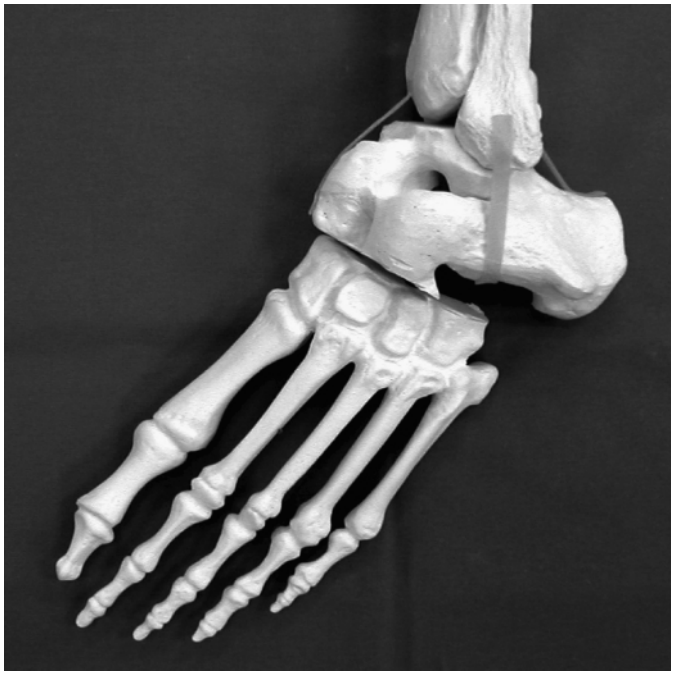

Fig. **4** Standardized osteotomy in the "Equinus Deformity" specimen.

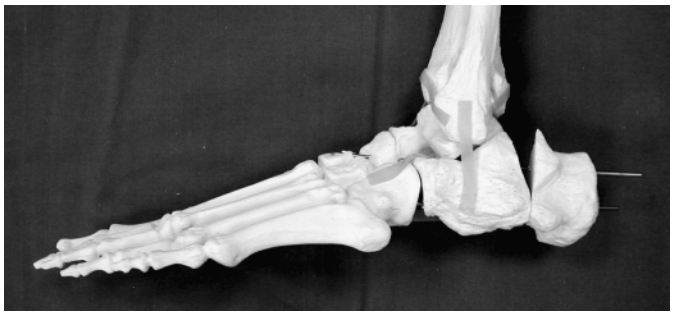

Fig. **5** Retention with K-wires after standardized osteotomy and correction in a "Calcaneus Malunion" specimen.

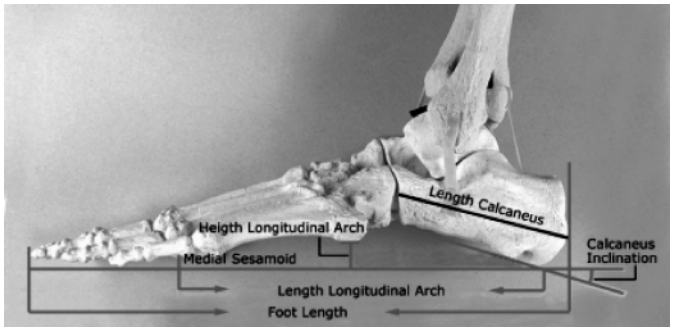

Fig. **6** Landmarks for measurements at normal and corrected specimens. The hindfoot angle and the calcaneus inclination were measured as described [49].

was longer in the CAS group although the time needed for the reduction process and the fluoroscopy time were shorter in the CAS group than in the C-arm group (Table **1**). In three cases in the CAS group, the system crashed down and was restarted (times for entire procedure in these cases 1000, 1010 and 1020 s).

Tables **1** and **2** indicate the measurements of specimens and measurement differences between the corrected specimens and the normal specimen model.

Discussion

In our experimental study, the accuracy of the correction of hind- and midfoot deformities with CT based CAS was higher than with the conventional C-arm based method.

When further analyzing the correction in the different pathology specimen models, the highest differences (lowest "t" values) between the CAS group and the C-arm group were observed in "Calcaneus Malunion" specimen model, followed by the "Equinus Deformity" and the "Equinovarus Deformity" specimen models. In both the "Calcaneus Malunion" and the "Equinus Deformity" specimens, an osteotomy was necessary for the correction, and the reduction process was more complex than in the "Equinovarus Deformity" specimen model. It seems that the accuracy of the CAS based correction is superior to the C-arm based correction in more difficult corrections. Especially the "Calcaneus Malunion" specimens required a complex and difficult reduction maneuver, similar to a clinical surgical procedure [29].

Table **1** Time use, measurements of specimens and measurement differences between the corrected specimens and the normal specimen model (mean values and range for times, and values and standard deviation for other measurements shown). Böhler's angle and calcaneus length were only corrected and assessed in the "Calcaneus Malunion" specimens (n = 5, CAS and C-arm each).

Parameter	*CAS (n = 15)*	*C-arm (n = 15)*	*t-test*
Times			
Time entire procedure	782 (450–1 020) s	410 (210–600) s	p < 0.001
Time reduction process	35 (28–54) s	98 (43–240) s	p = 0.02
Fluoroscopy time	0 s	11 (8–19) s	p < 0.001
Measurements of normal specimen model			
Foot length		*262.0 mm*	
Length longitudinal arch		*146.8 mm*	
Height longitudinal arch		*24.2 mm*	
Calcaneus inclination		*22.5°*	
Calcaneus length		*79.7 mm*	
Böhler's angle		*48°*	
Measurements of corrected specimens (all deformity models)			
Foot length	263.7 ± 1.9 mm	266.1 ± 3.8 mm	p = 0.03
Length longitudinal arch	147.7 ± 0.9 mm	152.4 ± 4.9 mm	p = 0.001
Height longitudinal arch	24.2 ± 0.5 mm	22.5 ± 4.3 mm	p = 0.14
Calcaneus inclination	22.4 ± 1.4°	19.8 ± 4.8°	p = 0.05
Calcaneus length	80.2 ± 0.4 mm	82.6 ± 1.3 mm	p = 0.005
Böhler's angle	47.6 ± 1.1°	43.9 ± 8.6°	p = 0.37
Measurements differences between corrected and normal specimens (all deformity models)			
Foot length	–1.7 ± 1.9 mm	–4.1 ± 3.8 mm	p = 0.03
Length longitudinal arch	–0.9 ± 0.9 mm	–5.6 ± 4.9 mm	p = 0.001
Height longitudinal arch	–0.1 ± 0.5 mm	1.7 ± 4.3 mm	p = 0.14
Calcaneus inclination	0.1 ± 1.4°	2.7 ± 4.8°	p = 0.05
Calcaneus length	–0.5 ± 0.4 mm	–2.8 ± 1.3 mm	p = 0.005
Böhler's angle	0.4 ± 1.1°	4.1 ± 8.6°	p = 0.37

Table **2** Significances (p-values of t-test) of differences between CAS and C-arm groups of measurement differences between corrected specimens and normal specimen of different pathology models

Parameter	*Calcaneus malunion*	*Equinus deformity*	*Equinovarus deformity*
p-values of t-test between CAS (n = 5) and C-arm (n = 5)			
Time entire procedure, CAS > C-arm	< 0.001	0.005	< 0.001
Time reduction process, CAS < C-arm	0.01	0.05	0.15
Fluoroscopy time, CAS < C-arm	< 0.001	0.002	0.003
Measurements differences between corrected and normal specimens			
Foot length, CAS < C-arm	0.03	0.02	0.81
Length longitudinal arch, CAS < C-arm	0.001	0.04	0.25
Height longitudinal arch, CAS < C-arm	< 0.001	0.7	0.82
Calcaneus inclination, CAS < C-arm	0.38	0.55	0.21
Calcaneus length, CAS < C-arm	0.004	Not corrected	
Böhler's angle, CAS < C-arm	0.005		

With CAS, the reduction process of the "Calcaneus Malunion" specimens was not found to be more difficult than for example in the "Equinovarus Deformity" specimens. In contrast, the C-arm based reduction of the "Equinovarus Deformity" specimens was much easier than the C-arm based reduction of the "Calcaneus Malunion" specimens. This is reflected by the shorter reduction process times in the "Equinovarus Deformity" specimens than in the "Calcaneus Malunion" specimens in the C-arm group (data not shown). The times needed for the reduction process with CAS were similar in all deformity specimen models (data not shown), and were significantly shorter than in the C-arm group. Furthermore, the fluoroscopy times were shorter in the CAS group than in the C-arm group because no intraoperative fluoroscopy was needed for CAS in comparison to 11 seconds fluoroscopy in average in the C-arm group. However, the time of the entire correction procedure needed for the CAS method was almost twice the time needed for the C-arm method.

The reasons for the longer time needed with CAS are the requirements of the data transfer of the DICOM-data of the preoperative 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 remain in the same position between the preoperative 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 less and bigger bones [6, 13, 14, 20, 28, 31]. In the clinical application of CAS in the foot, the problems with the registration will still increase, although the soft tissue coverage is favorably thin.

When the registration was finally finished, the CT based CAS as used in our study was more accurate and even easier and faster than the conventional C-arm based method, but the problems with the registration will prevent broad clinical use. Fortunately, at the time this experimental study was planned and performed, two novel CAS methods without registration were introduced, the C-arm based CAS and the ISO-3-D™ (Siemens AG, Germany) based CAS. The ISO-C-3D™ is a motorized C-arm that provides fluoroscopic images during a 190 degrees orbital rotation computing a 119 mm data cube. From these 3D data sets multiplanar reconstructions were obtained. In both the C-arm and ISO-3-D™ based CAS, the DICOM-data are registered intraoperatively with the C-arm or ISO-3-D™ which are connected with the CAS device. The markers are fixed to the bones before, which makes any registration unnecessary. The C-arm based CAS provides two-dimensional images, and the ISO-3-D™ based CAS even three dimensional images comparable to a CT based CAS. The C-arm based CAS and the ISO-3-D™ based CAS have been used in our institution experimentally and the C-arm based CAS was clinically used for the positioning of drill holes in ankle and/or subtalar arthrodeses (unpublished work). Both methods combine the accuracy of the CT based CAS as shown in this study without the stumbling block registration.

Another problem with the CAS device that was used in this study, and with other CAS devices is the software that is currently unsuitable for the planning of bony corrections or reductions. There is better planning software available on the market, and a modification of the software tools for planning in CAS devices seems to be a minor technical problem.

Another important issue are the device costs, that are much higher for the CAS (approx. 500 000 Euro) than for the C-arm alone (approx. 50 000 Euro). The device costs will even increase if C-arm based CAS (plus approx. 60 000 Euro for modified C-arm) or ISO-3-D™ based CAS (plus approx. 250 000 Euro for ISO-3-D™) are used. These higher costs will only be acceptable if the higher accuracy of CAS leads to better clinical results as with C-arm based methods.

In conclusion, CAS promises to be a valuable tool for higher accuracy for the correction of hind- and midfoot deformities and for the reduction in hind- or midfoot fractures and fracture-dislocations. Clinical studies must show if this higher accuracy can be achieved in real operations also, and if this leads to better clinical results. The clinical use of the CT-based CAS in the foot is complicated due to the difficult registration. Therefore, CAS methods without registration like C-arm based CAS and ISO-3-D™ based CAS, will be especially interesting for the foot region.

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References

[1] Adelaar RS. The treatment of complex fractures of the talus. Orthop Clin North Am 1989; 20 (4): 691 – 707
[2] Adelaar RS, Kyles MK. Surgical correction of resistant talipes equinovarus: observations and analysis – preliminary report. Foot Ankle 1981; 2 (3): 126 – 137
[3] Amon K. Luxationsfraktur der kuneonavikularen Gelenklinie. Klinik, Pathomechanismus und Therapiekonzept einer sehr seltenen Fußverletzung. Unfallchirurg 1990; 93 (9): 431 – 434
[4] Bailey EJ, Waggoner SM, Albert MJ, Hutton WC. Intraarticular calcaneus fractures: a biomechanical comparison or two fixation methods. J Orthop Trauma 1997; 11 (1): 34 – 37
[5] Bargar WL, Bauer A, Borner M. Primary and revision total hip replacement using the Robodoc system. Clin Orthop 1998; (354): 82 – 91
[6] Bechtold JE, Powless SH. The application of computer graphics in foot and ankle surgical planning and reconstruction. Clin Pediatr Med Surg 1993; 10 (3): 551 – 562
[7] Birkfellner W, Huber K, Larson A, Hanson D, Diemling M, Homolka P et al. A modular software system for computer-aided surgery and its first application in oral implantology [In Process Citation]. IEEE Trans Med Imaging 2000; 19 (6): 616 – 620
[8] Brutscher R. Frakturen und Luxationen des Mittel- und Vorfußes. Orthopäde 1991; 20 (1): 67 – 75
[9] Claes J, Koekelkoren E, Wuyts FL, Claes GM, Van Den HL, Van De Heyning PH. Accuracy of computer navigation in ear, nose, throat surgery: the influence of matching strategy [In Process Citation]. Arch Otolaryngol Head Neck Surg 2000; 126 (12): 1462 – 1466

[10] Coetzee JC, Hansen ST. Surgical management of severe deformity resulting from posterior tibial tendon dysfunction. Foot Ankle Int 2001; 22 (12): 944 – 949

[11] Delp SL, Stulberg SD, Davies B, Picard F, Leitner F. Computer assisted knee replacement. Clin Orthop 1998; 354: 49 – 56

[12] DiGioia AM III, Jaramaz B, Colgan BD. Computer assisted orthopaedic surgery. Image guided and robotic assistive technologies. Clin Orthop 1998; (354): 8 – 16

[13] DiGioia AM III, Jaramaz B, Plakseychuk AY, Moody JE Jr, Nikou C, Labarca RS et al. Comparison of a mechanical acetabular alignment guide with computer placement of the socket. J Arthroplasty 2002; 17 (3): 359 – 364

[14] Foley KT, Smith MM. Image-guided spine surgery. Neurosurg Clin N Am 1996; 7 (2): 171 – 186

[15] Gebhard F, Kinzl L, Arand M. [Computer-assisted surgery]. Unfallchirurg 2000; 103 (8): 612 – 617

[16] Gebhard F, Kinzl L, Arand M. [Limits of CT-based computer navigation in spinal surgery]. Unfallchirurg 2000; 103 (8): 696 – 701

[17] Hansen STJ. Functional reconstruction of the foot and ankle. Baltimore, New York: Lippincott Williams & Wilkins, Philadelphia 2000

[18] Hassfeld S, Muhling J. Navigation in maxillofacial and craniofacial surgery. Comput Aided Surg 1998; 3 (4): 183 – 187

[19] Hildebrand KA, Buckley RE, Mohtadi NG, Faris P. Functional outcome measures after displaced intra-articular calcaneal fractures. J Bone Joint Surg [Br] 1996; 78 (1): 119 – 123

[20] Jaramaz B, DiGioia III AM, Blackwell M, Nikou C. Computer assisted measurement of cup placement in total hip replacement. Clin Orthop 1998; 354: 70 – 81

[21] Kamimura M, Ebara S, Itoh H, Tateiwa Y, Kinoshita T, Takaoka K. Accurate pedicle screw insertion under the control of a computer-assisted image guiding system: laboratory test and clinical study. J Orthop Sci 1999; 4 (3): 197 – 206

[22] Kato A, Yoshimine T, Hayakawa T, Tomita Y, Ikeda T, Mitomo M et al. [Computer assisted neurosurgery: development of a frameless and armless navigation system (CNS navigator)]. No Shinkei Geka 1991; 19 (2): 137 – 142

[23] Kerschbaumer F. ["Numerical imaging, operation planning, simulation, navigation, robotics". Do the means determine the end? (editorial)]. Orthopade 2000; 29 (7): 597 – 598

[24] Klos TV, Banks SA, Habets RJ, Cook FF. Sagittal plane imaging parameters for computer-assisted fluoroscopic anterior cruciate ligament reconstruction. Comput Aided Surg 2000; 5 (1): 28 – 34

[25] Klos TV, Habets RJ, Banks AZ, Banks SA, Devilee RJ, Cook FF. Computer assistance in arthroscopic anterior cruciate ligament reconstruction. Clin Orthop 1998; 354: 65 – 69

[26] Koczewski P, Shadi M, Napiontek M. Foot lengthening using the Ilizarov device: the transverse tarsal joint resection versus osteotomy. J Pediatr Orthop B 2002; 11 (1): 68 – 72

[27] Laine T, Lund T, Ylikoski M, Lohikoski J, Schlenzka D. Accuracy of pedicle screw insertion with and without computer assistance: a randomised controlled clinical study in 100 consecutive patients [In Process Citation]. Eur Spine J 2000; 9 (3): 235 – 240

[28] Langlotz F, Bachler R, Berlemann U, Nolte LP, Ganz R. Computer assistance for pelvic osteotomies. Clin Orthop 1998; 354: 92 – 102

[29] Marti RK, de Heus JA, Roolker W, Poolman RW, Besselaar PP. Subtalar arthrodesis with correction of deformity after fractures of the os calcis. J Bone Joint Surg [Br] 1999; 81 (4): 611 – 616

[30] Merloz P, Tonetti J, Cinquin P, Lavallee S, Troccaz J, Pittet L. [Computer-assisted surgery: automated screw placement in the vertebral pedicle]. Chirurgie 1998; 123 (5): 482 – 490

[31] Merloz P, Tonetti J, Pittet L, Coulomb M, Lavallee S, Troccaz J et al. Computer-assisted spine surgery. Comput Aided Surg 1998; 3 (6): 297 – 305

[32] Mosier-LaClair S, Pomeroy G, Manoli A. Operative treatment of the difficult stage 2 adult acquired flatfoot deformity. Foot Ankle Clin 2001; 6 (1): 95 – 119

[33] Ploder O, Wagner A, Enislidis G, Ewers R. [Computer-assisted intraoperative visualization of dental implants. Augmented reality in medicine]. Radiologe 1995; 35 (9): 569 – 572

[34] Radermacher K, Portheine F, Anton M, Zimolong A, Kaspers G, Rau G et al. Computer assisted orthopaedic surgery with image based individual templates. Clin Orthop 1998; 354: 28 – 38

[35] Richter M, Wippermann B, Krettek C, Schratt E, Hufner T, Thermann H. Fractures and fracture dislocations of the midfoot – Occurrence, causes and long-term results. Foot Ankle Int 2001; 22 (5): 392 – 398

[36] Sammarco GJ, Conti SF. Surgical treatment of neuroarthropathic foot deformity. Foot Ankle Int 1998; 19 (2): 102 – 109

[37] Schiffers N, Schkommodau E, Portheine F, Radermacher K, Staudte HW. [Planning and performance of orthopedic surgery with the help of individual templates]. Orthopäde 2000; 29 (7): 636 – 640

[38] Schlenzka D, Laine T, Lund T. [Computer-assisted spine surgery: principles, technique, results and perspectives]. Orthopäde 2000; 29 (7): 658 – 669

[39] Schlenzka D, Laine T, Lund T. Computer-assisted spine surgery. Eur Spine J 2000; 9 Suppl 1: S57 – S64

[40] Stephens HM, Walling AK, Solmen JD, Tankson CJ. Subtalar repositional arthrodesis for adult acquired flatfoot. Clin Orthop 1999; 365: 69 – 73

[41] Suren EG, Zwipp H. Luxationsfrakturen im Chopart- und Lisfranc-Gelenk. Unfallchirurg 1989; 92 (3): 130 – 139

[42] Thoma W, Schreiber S, Hovy L. [Computer-assisted implant positioning in knee endoprosthetics. Kinematic analysis for optimization of surgical technique]. Orthopade 2000; 29 (7): 614 – 626

[43] Tonetti J, Carrat L, Blendea S, Merloz P, Troccaz J, Lavallee S et al. Clinical results of percutaneous pelvic surgery. Computer assisted surgery using ultrasound compared to standard fluoroscopy. Comput Aided Surg 2001; 6 (4): 204 – 211

[44] Tonetti J, Carrat L, Lavallee S, Pittet L, Merloz P, Chirossel JP. Percutaneous iliosacral screw placement using image guided techniques. Clin Orthop 1998; 354: 103 – 110

[45] Toolan BC, Sangeorzan BJ, Hansen Jr ST. Complex reconstruction for the treatment of dorsolateral peritalar subluxation of the foot. Early results after distraction arthrodesis of the calcaneocuboid joint in conjunction with stabilization of, and transfer of the flexor digitorum longus tendon to, the midfoot to treat acquired pes planovalgus in adults. J Bone Joint Surg Am 1999; 81 (11): 1545 – 1560

[46] Trnka HJ, Easley ME, Lam PW, Anderson CD, Schon LC, Myerson MS. Subtalar distraction bone block arthrodesis. J Bone Joint Surg Br 2001; 83 (6): 849 – 854

[47] Wei SY, Sullivan RJ, Davidson RS. Talo-navicular arthrodesis for residual midfoot deformities of a previously corrected clubfoot. Foot Ankle Int 2000; 21 (6): 482 – 485

[48] Weihe S, Wehmoller M, Schliephake H, Hassfeld S, Tschakaloff A, Raczkowsky J et al. Synthesis of CAD/CAM, robotics and biomaterial implant fabrication: single-step reconstruction in computer aided frontotemporal bone resection [In Process Citation]. Int J Oral Maxillofac Surg 2000; 29 (5): 384 – 388

[49] Zwipp H. Chirurgie des Fußes. Springer-Verlag, Wien, New York 1994

[50] Zwipp H, Dahlen C, Randt T, Gavlik JM. Komplextrauma des Fußes. Orthopäde 1997; 26 (12): 1046 – 1056