virtX – Evaluation of a Computer-based Training System for Mobile C-arm Systems in Trauma and Orthopedic Surgery

O. J. Bott[1, 2], M. Teistler[3], C. Duwenkamp[1], M. Wagner[1], M. Marschollek[1], M. Plischke[1], B. W. Raab[4], K. M. Stürmer[5], D. P. Pretschner[1], K. Dresing[5]
[1]Institute for Medical Informatics, Technical University of Braunschweig, Braunschweig, Germany
[2]University of Applied Sciences and Arts, Hannover, Germany
[3]Biomedical Imaging Lab, Agency for Science, Technology and Research (A*STAR), Singapore
[4]Department of Diagnostic Radiology, Georg August University, Goettingen, Germany
[5]Department of Trauma Surgery, Plastic and Reconstructive Surgery, Georg August University, Goettingen, Germany

Summary

Objectives: Operating room personnel (ORP) operating mobile image intensifier systems (C-arms) need training to produce high quality radiographs with a minimum of time and X-ray exposure. Our study aims at evaluating acceptance, usability and learning effect of the CBT system virtX that simulates C-arm based X-ray imaging in the context of surgical case scenarios.
Methods: Prospective, interventional study conducted during an ORP course with three groups: intervention group 1 (training on a PC using virtX), and 2 (virtX with a C-arm as input device), and a control group (training without virtX) – IV1, IV2 and CG. All participants finished training with the same exercise. Time needed to produce an image of sufficient quality was recorded and analyzed using One-Way-ANOVA and Dunnett post hoc test ($\alpha = .05$). Acceptance and usability of virtX have been evaluated using a questionnaire.
Results: CG members ($n = 21$) needed more time for the exercise than those of IV2 ($n = 20$): 133 $\pm$ 55 vs. 101 $\pm$ 37 sec. ($p = .03$). IV1 ($n = 12$) also performed better than CG (128 $\pm$ 48 sec.), but this was not statistically significant.
Seventy-nine participants returned a questionnaire (81% female, age 34 $\pm$ 9 years, professional experience 8.3 $\pm$ 7.6 years; 77% regularly used a C-arm). 83% considered virtX a useful addition to conventional C-arm training. 91% assessed virtual radiography as helpful for understanding C-arm operation.
Conclusions: Trainees experienced virtX as substantial enhancement of C-arm training. Training with virtX can reduce the time needed to perform an imaging task.

Keywords

CBT, mobile image intensifier systems, C-arm, virtual operation theater, trauma surgery, orthopedic surgery

Methods Inf Med 2008; 47: 270–278

doi:10.3414/ME0476

1. Introduction

In the treatment of emergency and trauma patients mobile C-arm image intensifier systems (abbrev. C-arm) are essential tools for a successful surgical outcome. But X-ray examinations are still potentially dangerous for patient and operating room personnel [1-5], although technical improvements in the last years have helped to reduce the amount of radiation (e.g. digital imaging, apertures, laser localizer beam) [6, 7].

During surgery the surgeon depends on the correct adjustment of the C-arm, which is normally operated by a nurse. Due to training deficiencies in C-arm operation the surgeon often needs to control the adjustments of the image intensifier during osteosynthesis by performing continuous X-ray imaging in the fluoroscopy mode. This increases the X-ray exposure dose. Furthermore, a lot of specific adjustments (e.g. acetabulum, calcaneus) are hard to achieve even by an experienced nurse. Better training of the nurses operating a C-arm would accelerate X-ray examinations during surgical interventions, thus reducing expensive surgical time and X-ray exposure of patients and the operating room personnel. Lacking the possibility to produce X-ray images for training purposes, C-arm operation is currently trained on a theoretical basis only. To gain the qualification needed to adjust the C-arm in a timely fashion with a minimum of radiation exposure, this theoretical training is insufficient and implies "training on the job" which means nothing else as "training on the patient".

As a means to provide students and residents with knowledge and the opportunity to interactively perform case-based exercises, computer-based training systems (CBTs) have gained increased attention in recent years in medical education as well as in radiology [9]. Interactive training programs based on case libraries for practicing image interpretation (e.g. [9-11]) have been developed and examined concerning their feasibility and usability. Partly the effects of these systems in terms of a better learning outcome were examined in comparison with conventional, mostly paper-based methods (see e.g. [12]). Furthermore, the combination of these CBTs with a medical atlas has been discussed [13]. Besides CBTs that focus on the correct interpretation of radiological images some simulators have been developed to practice e.g. interventional cardiology [14]. Systems like the one described in [14] offer a training environment that realistically simulates a specific manual medical procedure using suitable in- and output devices. To our knowledge currently no CBT focuses on the correct usage of C-arm systems to produce radiographs that meet the specific quality requirements of surgical interventions.

Received: February 2, 2007; accepted: October 21, 2007

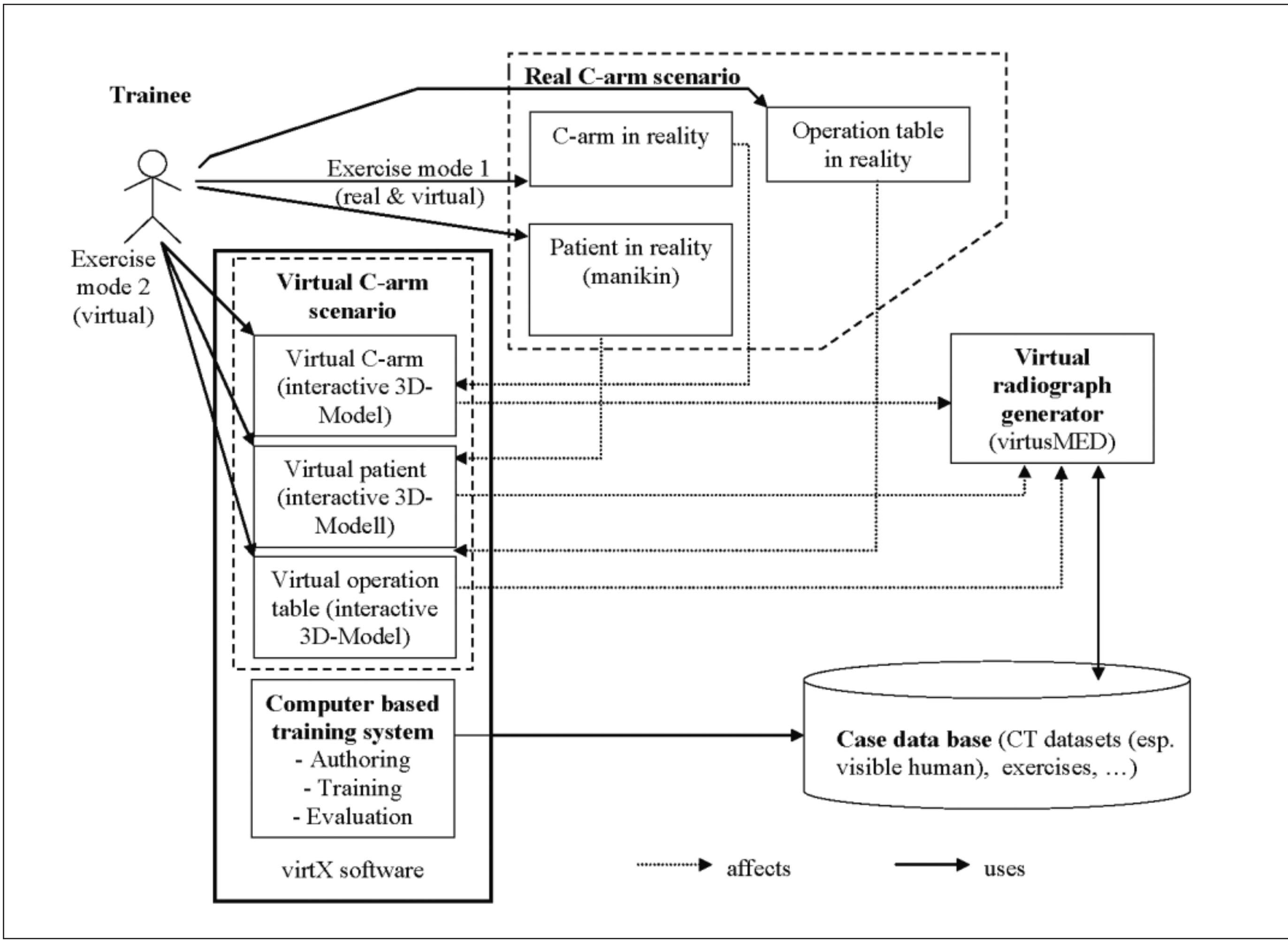

Fig. 1 virtX system concept

2. Objectives

The aim of this paper is to present a computer-based training system for C-arm operation, the virtX system, and the results of a first evaluation. The objective of the virtX system is to improve training and preparation of C-arm operation through simulating C-arm-based X-ray image production in the context of real surgical case scenarios. The questions of our study are:

- Q1: Does training with virtX reduce the time needed to accomplish an imaging exercise?
- Q2: How do potential users assess the virtX system's usability and suitability for training C-arm operation?

3. Methods

This chapter is divided into one section that describes the design, implementation and use cases of the virtX system, and a second section that describes the study design.

3.1 The virtX System

The virtX system has been developed by an interdisciplinary team consisting of medical informatics experts, trauma surgeons and radiologists. After an analysis of the current state of the art in C-arm education a new educational concept has been developed including the identification of CBT use cases followed by the design of the virtX system architecture. After a prototyping phase that aimed at a proof of concept and on finding suitable user interfaces the system was finally implemented. The resulting virtX system consists conceptually of five components (see Fig. 1):

1) a real C-arm scenario (RCS) consisting of a C-arm device, an operating table and an artificial patient in the form of a manikin,
2) a virtual C-arm scenario (VCS) consisting of interactive graphical 3D models of the RCS objects,
3) a virtual radiograph generator (VRG),
4) a computer-based training system including an authoring system for case-

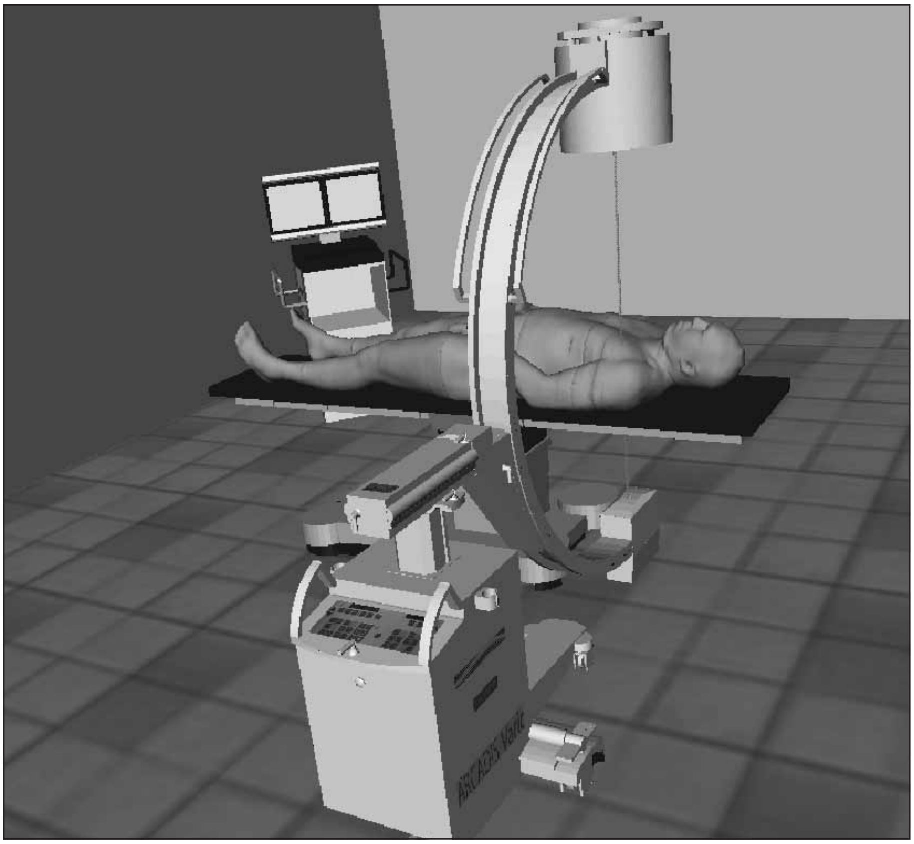

Fig. 2 3D models of C-arm, operation table and patient in a virtual operation theater

based exercises, and a training and evaluation module for performing these exercises,
5) a case data base with exercises and CT data sets.

virtX is independent of any specific C-arm or operation table. The RCS currently consists of an ARCADIS Varic C-arm from Siemens Medical Solutions and an operating table system from Maquet. The manikin is realized using a Styrofoam patient dummy, which was made using a 3D surface model of the Visible Human male [15] through cutting out and gluing panes of approximately 2 cm thickness. The interactive 3D models of the VCS (see Fig. 2) were constructed using the open source software systems Coin3D [16] and Blender [17].

The whole C-arm and all of the five joints and rails of the C-arm can be interactively moved in a virtual operating room. A selected set of joints and rails of the operating table can also be manipulated interactively. The virtual patient currently can not be altered concerning his posture.

The VRG is built upon 'virtusMED' (virtual scenes for medical education and diagnostics), a system that allows for a new kind of interactive visualization of volumetric medical images [18, 19] usable for education or diagnosis [20]. Based on CT and MRI data sets in DICOM [21] format as well as on data from the Visible Human Project [22] virtusMED creates a virtual patient that can be explored in real-time by an ultrasound-like probe, a head-mounted display and/or a freely movable flat panel. In particular it allows for the generation of virtual radiographs from any direction based on an arbitrary CT data set.

The virtX-CBT is an application program that presents the trainee predefined exercises he has to accomplish. Each exercise is related to a clinical case category and combines visual radiological information needed by the surgeon at a specific step of a surgical procedure like a clear view into the knee joint space with the corresponding adjustment of the C-arm that has to be achieved by the trainee. virtX-CBT controls the achievement of the correct position and orientation of the C-arm in relation to the virtual patient and measures the amount of (virtual) radiation needed to produce the images. The success of the trainee concerning an exercise is dependent on the total time needed to accomplish the task, the amount of radiation needed, the correctness of the position and orientation of the C-arm related to the patient, and the correct usage of the control features of the C-arm when producing and finishing the images. After accomplishing an exercise the trainee receives direct feedback concerning his personal success rate in comparison with an expert in C-arm operation.

When using the CBT the trainee is faced with four 3D views on the operation theater and two views on the radiographs produced by the VRG. The views are arranged in two windows each one filling one of altogether two monitors (see Fig. 3). The main and largest 3D view on the left screen presents the operation theater from the position of the trainee, which operates the C-arm from behind the device. The second 3D view on the left screen depicts the conducting laser beam of the C-arm and the position on the patient, where the beam impinges. The small radiograph view on the left screen displays in real time the results of the C-arm if operated in the fluoroscopy mode. The move and control buttons of the virtual C-arm are positioned in the lower left part of the left screen. In the lower right part of the left screen the trainee can use buttons to receive general help regarding virtX or to receive an explanation of the exercise including quality criteria for the radiograph and a sample radiograph. A traffic light icon above the buttons signalizes if the trainee is too far from (red light) or nearby (yellow) the correct adjustment of the C-arm, or if he has reached the correct adjustment (green). Directly under the traffic light icon a horizontal bar summarizes the amount of radiation needed so far.

The two 3D views on the right screen present the operation theater from the position of the surgeon and from the ceiling of the operation theatre. The big radiograph

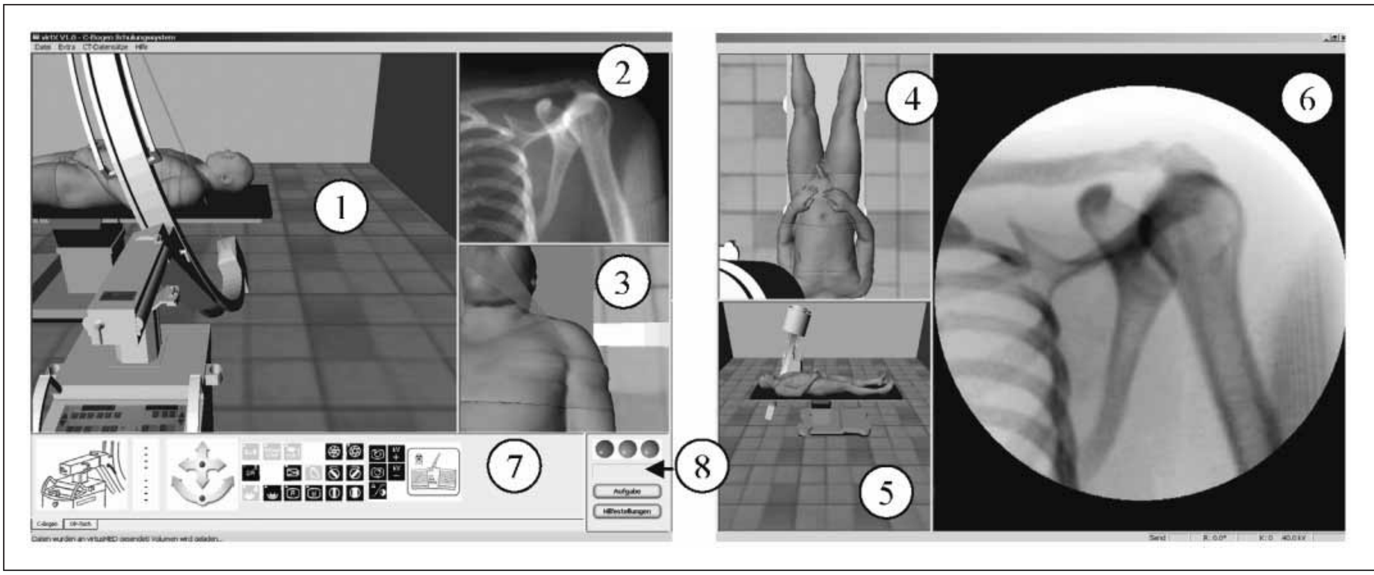

Fig. 3 User interfaces of the virtX CBT presented on two monitors. 1) Virtual operation theater and C-arm from the position of the C-arm operator. 2) Virtual radiograph (fluoroscopy mode). 3) View from the image intensifier onto the patient including the conducting laser beam. 4) View from the ceiling of the virtual operation theater above the patient. 5) View from the position of the surgeon. 6) Virtual radiograph (single image mode). 7) Virtual C-arm controls. 8) User interface elements for exercise control and feedback

view on the right screen depicts the radiograph produced using the single picture mode of the C-arm.

The virtX-CBT additionally offers an authoring tool for defining exercises on the basis of suitable CT data sets. Data sets were taken from day-to-day clinical cases using a computed tomography (CT) scanner with multidetector technology (MDCT). Depending on scan collimation and slice thickness during helical data acquisition a 3D-volume data set with nearly isotropic voxels can be achieved. This volume data set can be used for further image reconstructions with virtX after importing the CT data set with a virtX DICOM import tool.

To create an exercise the author first selects a C-arm, an operation table, and a virtual patient, the latter in form of a 3D surface model. Then he defines the initial positions and adjustments of the C-arm, the patient, and the operation table. After importing as many CT data sets as needed with the DICOM import tool the author registers the CT data sets manually with the corresponding area of the virtual patient by translation, rotation, and scaling operations (Fig. 4).

After registration of suitable CT data sets the author defines the sequence of subtasks of an exercise, i.e. a sequence of radiographs. An example is the ankle joint exercise consisting of the subtasks ankle joint a.-p., a.-p. with 15-20° internal rotation and ankle joint lateral. Each subtask is defined by data concerning the correct position and orientation and the correct control sequence of the C-arm. The author also defines the maximum time to adjust the C-arm correctly and he defines the maximum amount of radiation a professional operator would originate while producing the requested radiographs. The author furthermore adds a description including criteria for a good radiograph like "fibula aligned with the

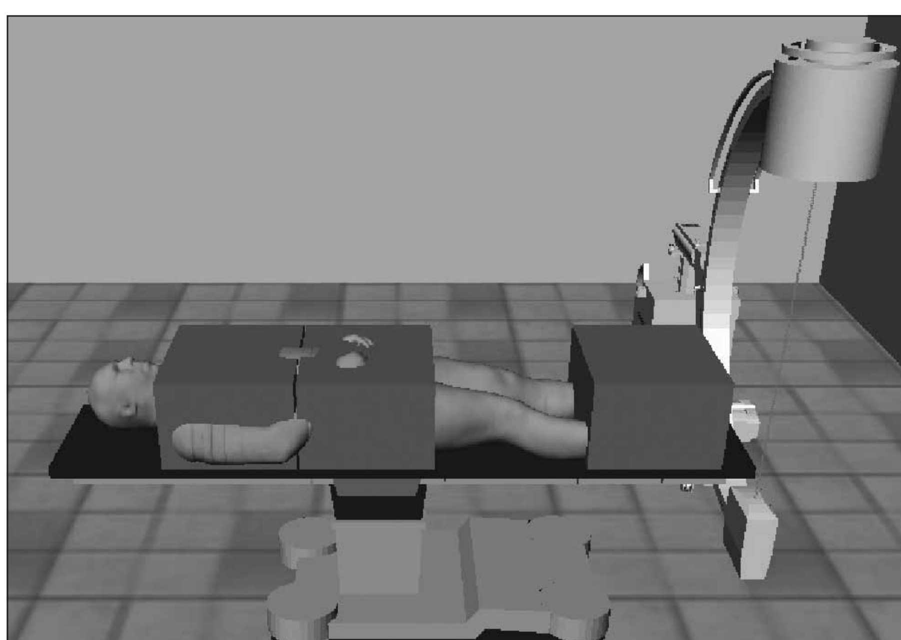

Fig. 4 Registration of three CT data sets (depicted as boxes) with a 3D surface model of a virtual patient on the example of the Visible Human data set

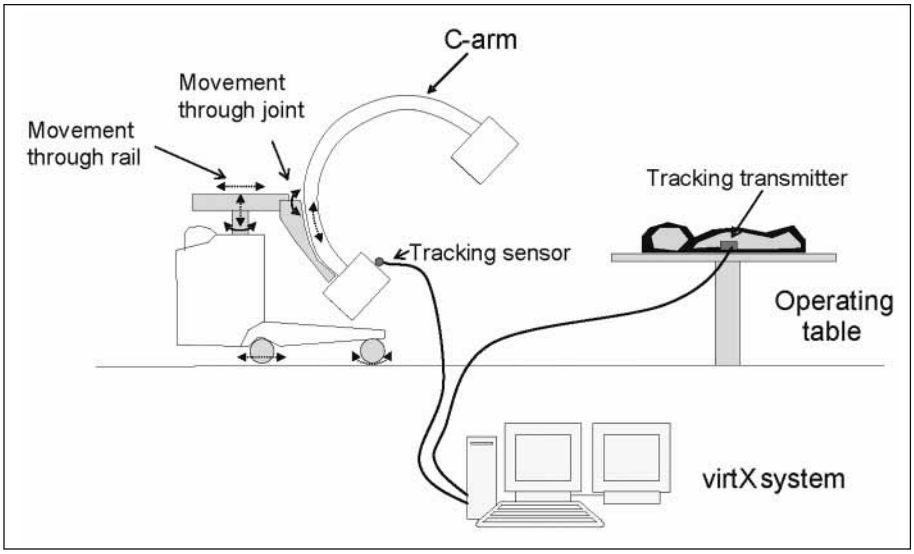

Fig. 5 Electromagnetic tracking of the C-arm in virtual/real mode

middle to lower part of the tibial joint surface" in case of the ankle joint lateral subtask and he adds an example radiograph. Each exercise definition can be stored in a case database.

A first 3D surface model for embedding CT data sets was derived from the Visible Human Project data set (see Fig. 3). It was generated by segmentation based on the photographic slice images of the Visible Human. The Visible Human data set has the advantage of already containing a complete CT body scan that can exactly be registered with the corresponding 3D surface model. Thus at least this registered CT data set with no pathological structures is available when starting virtX. If needed it can be replaced or complemented by other CT data sets as described above.

The trainee can use the virtX-CBT in two modes: a virtual mode and a combined virtual/real mode. In the virtual mode the exercises are accomplished completely within the VCS by using the virtual 3D representations of the C-arm, the operation table and the patient. In the combined virtual/real mode the trainee works within the RCS combined with the VCS by using a real C-arm instead of its 3D representation to adjust its position and orientation related to a manikin that lies on a real operation table. Position and orientation of the C-arm in relation to the patient dummy are measured using an electromagnetic motion tracking sensor (see Fig. 5). Both Polhemus Fastrak [23] and Ascension pciBird [24] have been used successfully. Receiver and transmitter of the tracking sensor are mounted on the foot of the C of the C-arm and on the operation table within the patient dummy.

The data concerning position and orientation of the C-arm in relation to the patient dummy in the RCS are used to correspondently alter the position and orientation of the VCS in real-time. This requires a manual registration of the virtual 3D scene with the corresponding elements of the RCS when configuring the virtX. Especially the manikin needs to correspond to the 3D surface model of the VCS. This has been achieved through using an immobile manikin corresponding to the 3D surface model of the virtual patient.

To control the C-arm functionalities the trainee uses the virtX user interface due to the impossibility to log the user's interaction with the keyboard and the original application software of the C-arm. When the trainee achieves the probable correct adjustment of the C-arm in RCS he uses the virtX VCS interface to produce X-ray images in single picture or in the fluoroscopy mode.

To achieve an X-ray simulation at interactive rates, a simple approach aiming at fast generation of subjectively realistic X-ray images was chosen over an approach aiming at a physically correct simulation. Sum-intensity volume rendering based on 3D textures [25] is utilized, as this is based on OpenGL features that are accelerated by modern graphics hardware. A virtual camera is used to simulate the X-ray detector. A perspective view of a volume is computed that is reconstructed from CT slice images. Rendering is done using a transfer function that maps each voxel (volume element) intensity to an alpha (opacity) value as follows:

$$\alpha = \frac{\left(\frac{HU + 1024}{4095}\right)^k}{c}$$

HU is the CT attenuation in Hounsfield units ($-1024 \leq HU \leq 3071$), $k \geq 1$ an optional polynomial amplification, and c can be considered as virtual X-ray intensity ($c \geq 1$). The rendered image is then inverted to produce the final virtual X-ray image as seen in Figure 3.

3.2 Study Design

The virtX system has been evaluated during a three-day training course for operating theater personnel in November 2005 in Göttingen, Germany [26] based on a prospective, interventional study design with three groups: intervention group 1 (virtX training in virtual mode, i.e. using only a PC), intervention mode 2 (virtX training in virtual/real mode, i.e. combined with a real C-arm) and a control group (conventional training without virtX). The 120 participants were offered to enroll blindly for one of these three groups for practicing the operation of a C-arm. The enrolling process was designed to result in study groups of almost equal size based on block randomization with blocks of same length. Three exercises have been prepared for the course, two for training purposes (E1 and E2) and one (E3) for analyzing the exercise completion time for participants of intervention groups 1, 2 and the control group due to question Q1:

1) *Exercise 1 (E1): Free training* with CT data from the Visible Human Project of the hip and the torso. This exercise was created to enable the trainee to get familiar with the user interface of virtX in the virtual mode. No adjustments or target positions were defined for this task.

2) *Exercise 2 (E2):* Two subtasks concerning the *knee* were defined. The first sub task demands a radiograph of the knee joint a.-p., and the second demands a radiograph from lateral (knee joint lateral). Descriptions, target adjustments, time and radiation frames for both subtasks had been defined before through experts. A CT scan from a person with pathological changes (a multi-fragmentary, intraarticular fracture of the proximal tibia) was chosen for this exercise.
3) *Exercise 3 (E3):* The last exercise concerns the *ankle joint*. Three subtasks were defined corresponding to three radiographs, which should be produced routinely during the operation of an ankle joint fracture: Ankle joint from a.-p., ankle joint a.-p. with 15-20° internal rotation and ankle joint lateral. Descriptions, target adjustments and time and radiation frames for all subtasks had been defined through experts. A CT scan from a person with no pathological changes was chosen for this task.

Fig. 6 C-arm training with virtX in the virtual/real mode using a patient dummy made of Styrofoam on an operation table

After a general introduction of virtX at the first day for all participants of the course the participants got the opportunity to enlist in one of six training groups to practice at day two or three of the course. Hundred participants enrolled, 82 actually appeared. Each group comprised 10-20 persons and had a time frame of 30-60 minutes to practice. Four virtX training stations were made available, two for the pure virtual mode and two for the virtual/real mode (see Fig. 6). Each virtual mode workstation was attended by one instructor experienced in virtX, each virtual/real mode workstation was additionally attended by an experienced C-arm operator.

At the beginning of a training session each group got an introduction of C-arm operation, virtX and the exercises. After this introduction the participants were distributed over the four workstations. The pure virtual mode workstations were used for the free training exercise (E1), the virtual/real workstations were used for the knee (E2) and the ankle joint exercises (E3). Dependent on their assignment to one of the study groups the participants passed through a different training program:

1) The *control group C* performed E3 directly after an explanation of the exercise.
2) The *intervention group 1* (IV1) trained C-arm operation using the virtual mode (E1+E2) and then performed E3.
3) The *intervention group 2* (IV2) trained C-arm operation using the virtual mode (E1), trained additionally in the virtual/real mode (E2) and then performed E3

For E3 and each participant the time to accomplish the exercise with a sufficient final adjustment of the C-arm was recorded. The hypotheses due to Q1 are that the mean times for accomplishing E3 of intervention groups 1 and 2 are smaller than the mean time of the control group. For testing these hypotheses One-Way ANOVA ($\alpha = 0.1$) and pairwise multiple comparisons with a control using Dunnett's test ($\alpha = 0.05$) were used after checking the correspondence of the data with normal distributions using the Shapiro-Wilk test ($\alpha = 0.05$). Statistical analysis was conducted with the Statistical Package for Social Sciences (SPSS Version 13.0.1, Chicago, IL, USA).

After practicing each participant was asked to fill in an anonymous questionnaire due to question Q2 of our study. The questionnaire asked for age, gender, profession, years of professional experience, experience with computers, experience with C-arm operation, and the kind of tasks performed with virtX. Nine statements concerning the virtX system were posed allowing the participants to (strongly) agree or (strongly) disagree or to be undecided (neutral) according to the Likert scale. The questions regard 1) the usefulness of virtX for practicing C-arm operation in general, 2) the quality of the introduction to virtX, 3) the usefulness of the simulated radiographs, 4) the usefulness of the combination of a real C-arm with its virtual representation, 5) the usefulness of the Styrofoam patient dummy to help finding the correct adjustment, 6) the usefulness of practicing with virtX when using solely the virtual mode, 7) the usefulness of the 3D views of the virtual C-arm scenario, 8) the quality of the user-interface of the virtual C-arm, and 9) the need for obtaining virtX with every C-arm to ease the training of operation theatre personnel. Additionally each participant could make some remarks concerning which aspects of virtX are appealing and which are dissatisfying. They could also make sug-

Table 1 Exercise completion times for each study group (intervention groups 1 and 2, control group)

Group	n	Mean time (sec)	SD	Median time
C	21	133	55	126
IV1	12	128	48	118
IV2	20	101	37	93

gestions to improve virtX and give general remarks.

4. Results of the Exercise Data Analysis

Altogether 223 results of accomplishing a subtask of E3 from 82 participants were recorded. After eliminating apparent outliers due to human errors in time measurement the remaining subtask data records were added whenever three valid records for each subtask of E3 were available for one participant (see Table 1). This led to 12 records respectively participants for intervention group 1, 20 records for intervention group 2 and 21 records for the control group. For each of the groups the Shapiro-Wilk test for normal distribution resulted in affirmation of this assumption.

Figure 7 presents the Boxplots of the data of each study group (smallest observation, lower quartile, median, upper quartile, largest non-outlier observation and outlier). Dunnett's test revealed a statistically significant smaller exercise completion time of intervention group 2 compared with the control group ($p = 0.03$). The average exercise time of intervention group 1 is lower than the average exercise time of the control group, but the difference is not statistically significant.

5. Results of the Questionnaires

Altogether 79 of 82 participants (response rate: 96%) returned a filled in questionnaire[a]. The average age of the 62 female and 15 male participants was 34 ± 9 years (78 participants answered this question). Seventy-seven participants were nurses, one was additionally a surgeon and two had other occupations. The average number of years of professional experience was 8.3 ± 7.6 years (76 answers). Eighteen persons (23%) declared that they work casually with a C-arm, 61 (77%) regularly work with it (a Chi-square test concerning dependency of experience and study group resulted in no significant difference ($p = 0.266$)). Concerning the PC experience 3 participants (4%) mentioned no experience, 33 (43%) casually work with a PC and 41 (53%) regularly work with a PC (two did not answer this question). The results of the questionnaires are summarized in Table 2.

The possibility to add free text remarks has been used extensively: 52 participants gave a comment concerning what they liked most, 28 participants concerning what they did not like, 18 concerning possible improvements, and 26 gave a general comment. The most often positive aspect mentioned is the new possibility to practice C-arm imaging without radiation and with a real C-arm in a way that is close to reality. Comments from the participants suggested potential improvements for the following areas: a more realistic, flexible patient dummy, the degree of realism of the 3D operation theater, reducing the complexity of the user interface in the virtual mode, the integration of other C-arms and operating tables, faster computation of the radiograph, and a broader spectrum of exercises. Eight comments directly recommended to integrate virtX in courses for ORP, three participants had a negative attitude concerning this.

[a] Results of a preliminary questionnaire analysis can be found in [27].

6. Discussion

6.1 Questionnaire-based Evaluation

Supported by more than 83% agreement the results of the questionnaire are positive with regard to the acceptance of virtX as an extension of the conventional training of C-arm operation. Almost all (91%) of the participants emphasized in their answer to the corresponding question and in their personal comments the value of the X-ray image simulation as a substantial enhancement of the conventional, rather theoretically oriented education. Also the combination of the CBT with real devices (the virtual/real-mode) was assessed important for the training effect of the system (more than 84% agreement) whereas the pure virtual mode was assessed helpful by only 53%. I.e. that even though the user interface for controlling the virtual C-arm was accessed usable by nearly 80% of the participants the experience of controlling a real C-arm could not totally be substituted by the virtual C-arm. This supports the hypo-

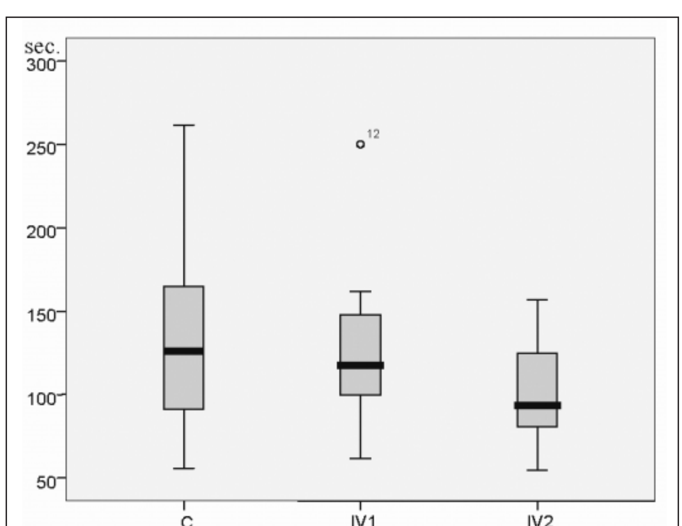

Fig. 7 Boxplots of the time needed to complete the exercise for the control group (n = 21), intervention group 1 (n = 12, one outlier), and intervention group 2 (n = 20)

Table 2 Results of the questionnaire (n = 79)

Question/statement	Answers	n.a.	strongly disagree	disagree	undecided	agree	strongly agree	Mean ± SD
1. virtX is an useful addition to conventional C-arm training.	78	1 %	1 %	4 %	10 %	17 %	67 %	4.4 ± 0.92
2. The introduction into the virtX CBT system was sufficient.	79	3 %	0 %	5 %	15 %	34 %	43 %	4.08 ± 0.88
3. The simulation of the X-ray imaging is helpful to understand the way a C-arm works.	78	1 %	0 %	3 %	5 %	24 %	67 %	4.51 ± 0.71
4. The combination of virtual training and operating a real C-arm is helpful.	76	0 %	0 %	5 %	11 %	21 %	63 %	4.42 ± 0.88
5. The patient dummy made of Styrofoam is sufficient for orientation.	78	0%	0%	2 %	8 %	27 %	63 %	4.5 ± 0.75
6. The four 3D views of the virtX user interface on the operation theatre are sufficient to position the C-arm unerringly.	78	5 %	6 %	9 %	8 %	49 %	23 %	3,58 ± 1.12
7. Using solely the virtual mode is helpful for practicing the correct adjustment of a C-arm.	78	1 %	4 %	17 %	26 %	29 %	23 %	3,47 ± 1.14
8. I've had no problems with the user interface for controlling the virtual C-arm.	79	5 %	1 %	5 %	9 %	39 %	41 %	3,97 ± 0.91
9. Every C-arm should be equipped with a CBT system like virtX.	79	3 %	1 %	6 %	15 %	24 %	51 %	4,09 ± 1.01

(1 = strongly disagree, 5 = strongly agree, n.a. = no assessment)

theses that the acceptance of a CBT for training the use of a medical device depends on the degree of interactivity and realism of the user interface.

Although the Styrofoam dummy is only a coarse representation of the virtual patient due to the thick panes it was made of, its usability was assessed sufficient for orientation by nearly 90% of the participants. An explanation for this surprising good acceptance may be that the direct visible feedback of the virtX system in the form of the X-ray image and partly in the form of the views on the virtual operation theater has outweighted the inaccuracy of the dummy.

virtX can be used in at least three scenarios. First, as a personal training system in the home environment of the trainee. Because of the costs of a C-arm and the tracking system only the virtual-mode version of virtX seems to be realistically applicable in this scenario. The second scenario is the use of virtX by commercial training service providers or C-arm producers that offer their training services in form of courses in clinical facilities or training centers. The third scenario is the use of virtX in the context of instruction courses organized and accomplished by clinical facilities themselves. For the latter two scenarios the virtual/real mode version of virtX in combination with a real C-arm is applicable. To equip C-arm systems with virtX would support these two scenarios. The results of the questionnaires show that most of the participants (75%) would appreciate the enhancement of C-arm systems with a CBT like virtX.

6.2 Accuracy of the X-ray Image Simulation

The chosen approach to the simulation of radiographs is a simple one that makes use of readily available hardware-accelerated visualization techniques to allow for real-time changes of the view direction. It represents a rough approximation rather than a physically correct simulation, since effects like shadows produced by the table or the automatic image optimization of the C-arm hard- and software are not taken into consideration. Yet, it provides views that are subjectively rated as sufficient for the aimed purpose by experienced surgeons. In addition none of the 79 participants that filled in a questionnaire mentioned a problem with deviations from radiographs produced by a real C-arm even though 77% claimed that they work regularly with a C-arm.

6.3 Exercise Data Analysis

The hypothesis that the *acceptance* of a CBT for training the use of a medical device depends on the degree of interactivity and realism of the CBT user interface can be extended to the hypothesis that the *effect* of such a system also depends on these properties. Whereas the first hypothesis is supported by the results of the questionnaires, the slightly better exercise results of the virtual/real-mode group compared with the virtual-mode group support the latter hypothesis. But the difference is not statistically significant. Concerning the effect of using virtX in the virtual/real-mode compared with conventional training of C-arm operation based on theoretical explanations and hands-on training without actual or simulated radiography a statistic significant difference of the time needed to achieve a correct adjustment could be shown. Thus a positive training effect at least of the virtual/real-mode of virtX can be assumed. Maleck et al. report similar results concerning the impact of interactivity on the effect of a CBT in the context of teaching radiology to medical students [12].

6.4 Study Design

Because of the study design with three groups and a tight course organization the numbers of sound data sets recorded for each group were relatively small – even if sound data sets could have been collected for altogether 52 participants. Especially only 12 data sets for intervention group 1 were available for statistical analysis. Additionally remarkable is that all of the participants had already frequent or regular experience with a C-arm. A further study that focuses solely on C-arm beginners would be of interest.

The study design focuses on short-term training effects. The final exercise was performed shortly after the training with or without virtX. Thus no statement can be made concerning the long-term effect of using virtX. This has to be analyzed in further studies.

It would have been more valuable to examine the performance of the trainees in the operating theater after they had received training conventionally or with virtX. Because the participants of the course came from throughout Germany this was not feasible. Thus further studies are needed to examine the effect of different training modalities on the time and the X-ray dosages needed to produce a radiograph, and the quality of the resulting image in the context of real operations.

7. Conclusion and Perspectives

The evaluation results reveal a high degree of acceptance of the virtX system by ORP trainees. virtX was experienced as a substantial enhancement of conventional C-arm training. It has been shown that using virtX has a significant effect on the performance of the trainees concerning the production of a requested radiograph when combining the virtual training environment with real devices.

Enhancements of virtX are planned towards the introduction of a virtual patient that can be interactively altered in his position on the operation table. For this it has to be analyzed in which way the CT data sets have to be modified to follow the movements of the virtual patient. Furthermore the patient dummy respectively its limbs, head, etc. needs to be made movable and equipped with more tracking sensors to register its movement with the virtual patient.

Acknowledgments

We would like to thank C.A. Ahrens, J.H. Grobe, R. Kimmel, and A. Lörchner for their help during the project, B. Wiese for her advice on statistical issues, Dr. J. Dormeier for his work concerning the virtualization of the Visible Human, and Siemens Medical Solutions, Erlangen (Germany) and Maquet, Rastatt (Germany) for supporting the project.

References

1. Bahari S, Morris S, Broe D, Taylor C, Lenehan B, McElwain J. Radiation exposure of the hands and thyroid gland during percutaneous wiring of wrist and hand procedures. Acta Orthop Belg 2006; 72: 194-198.
2. Fuchs M, Modler H, Schmid A, Dumont C, Sturmer KM. Measuring intraoperative radiation exposure of the trauma surgeon. Measuring eye, thyroid gland and hand with highly sensitive thermoluminescent detectors. Unfallchirurg 1999; 102: 371-376. In German.
3. Fuchs M, Schmid A, Eiteljorge T, Modler H, Sturmer KM. Radiation dosage of the surgery from intraoperative roentgen procedures: risks and dose management in the operating room. Langenbecks Arch Chir Suppl Kongressbd 1998; 115: 1111-1113. In German.
4. Mastrangelo G, Fedeli U, Fadda E, Giovanazzi A, Scoizzato L, Saia B. Increased cancer risk among surgeons in an orthopaedic hospital. Occup Med (Lond) 2005; 55: 498-500.
5. Singer G. Occupational radiation exposure to the surgeon. J Am Acad Orthop Surg 2005; 13 (1): 69-76.
6. Harris I, Walker PM, Trieu L. Radiation exposure using laser guide in orthopaedic procedures. ANZ J Surg 2002; 72: 349-351.
7. Robinson,AH, Moiz M, Hallett JP. Use of a laser guide to reduce screening time for the dynamic hip screw. Injury 1996; 27 (10): 713-714.
8. Schulz S, Schrader U, Klar R. Computer-based training and electronic publishing in the health sector: tools and trends. Methods Inf Med 1997; 36 (2): 149-153.
9. Trumm C, Dugas M, Wirth S, Treitl M, Lucke A, Kuttner B, Pander E, Clevert DA, Glaser C, Reiser M. Digital teaching archive. Concept, implementation, and experiences in a university setting. Radiologe. 2005; 45 (8): 724-734. In German.
10. Dugas M, Trumm C, Stabler A, Pander E, Hundt W, Scheidler J, Bruning R, Helmberger T, Waggershauser T, Matzko M, Reiser M. Case-oriented computer-based-training in radiology: concept, implementation and evaluation. BMC Med Educ 2001; 1: 5. Epub 2001 Oct 19.
11. Grunewald M, Heckemann RA, Gebhard H, Lell M, Bautz WA. COMPARE radiology: creating an interactive Web-based training program for radiology with multimedia authoring software. Acad Radiol 2003; 10 (5): 543-553.
12. Maleck M, Fischer MR, Kammer B, Zeiler C, Mangel E, Schenk F, Pfeifer KJ. Do computers teach better? A media comparison study for case-based teaching in radiology. Radiographics 2001; 21 (4): 1025-1032.
13. Garlatti S, Sharples M. The use of a computerized brain atlas to support knowledge-based training in radiology. Artif Intell Med 1998; 13 (3): 181-205.
14. Dawson SL, Cotin S, Meglan D, Shaffer DW, Ferrell MA. Designing a computer-based simulator for interventional cardiology training. Catheter Cardiovasc Interv. 2000; 51 (4): 522-527.
15. Spitzer V, Ackerman MJ, Scherzinger AL, Whitlock D. The Visible Human Male: A technical report. In J Am Med Inf Ass 1996; 3 (2): 118-130
16. www.coin3d.org (last accessed: February 1, 2007)
17. www.blender.org (last accessed: February 1, 2007)
18. Teistler M, Bott O, Dormeier J, Pretschner DP. Virtual Tomography: A New Approach to Efficient Human-Computer Interaction for Medical Imaging. In: R.L. Galloway Jr. (ed.): Proceedings of SPIE Vol. 5029, Medical Imaging 2003: Visualization, Image-Guided Procedures, and Display. 2003. pp 512-519.
19. Teistler M, Breiman RS, Lison T, Bott OJ, Pretschner DP, Aziz A, Nowinski WL: Simplifying the exploration of volumetric images: Development of a 3D user interface for the radiologist's workplace. J Digit Imaging 2007; Mar 27 (Epub ahead of print)..
20. Marschollek M, Teistler M, Bott OJ, Stuermer KM, Pretschner DP, Dresing K. Pre-operative dynamic interactive exploration of complex articular fractures using a novel 3D navigation tool. Methods Inf Med 2006; 45 (4): 384-388.
21. Graham RN, Perriss RW, Scarsbrook AF. DICOM demystified: a review of digital file formats and their use in radiological practice. Clin Radiol 2005; 60 (11): 1133-1140.
22. Hohne KH, Pflesser B, Pommert A, Riemer M, Schubert R, Schiemann T, Tiede U, Schumacher U. Abstract: A realistic model of human structure from the visible human data. Methods Inf Med 2001; 40 (2): 83-89.
23. Fastrak, Polhemus Inc., Colchester, VT, U.S. Online: http://www.polhemus.com/?page=Motion_Fastrak (last accessed: February 1, 2007)
24. pciBird. Ascension Technology Corporation, Burlington, VT, U.S. Online http://www.ascension-tech.com/products/pcibird.php (last accessed: February 1, 2007)
25. 3D Texture Volume Rendering. In: McReynolds T, Blythe D (eds.). Programming with OpenGL: Advanced Rendering. Silicon Graphics Inc. (SGI), Mountain View, CA, U.S., 1997. Online: http://www.opengl.org/resources/code/samples/advanced/advanced97/notes/node181.html (last accessed: February 1, 2007)
26. Homepage of the AO Foundation: New training tool launched at first AO Course for ORP, http://www.aofoundation.org/portal/wps/portal/!ut/p/_s.7_0_A/7_0_A1T?contentUrl=/wor/net/or_personnel/news/2006/ao_extranet_news_00000312.jsp&hidenews=true (last accessed: February 1, 2007)
27. Bott OJ, Wagner M, Duwenkamp C, Kimmel R, Lörchner A, Ahrens CA, Grobe J-H, Raab B, Stürmer KM, Pretschner DP, Dresing K. virtX – Computer-based system for practicing mobile image intensifier systems in ambulance and operation theatre. In: GMS Med Inform Biom Epidemiol 2006; 2 (3): Doc16 (20061123). In German.

Correspondence to:
Oliver J. Bott
University of Applied Sciences and Arts Hannover
Faculty III – Media, Information and Design
Expo Plaza 12
30539 Hannover
Germany
E-mail: oliver.bott@fh-hannover.de