

Comparison of Multidetector Computed Tomography and Flat-Panel Computed Tomography Regarding Visualization of Cortical Fractures, Cortical Defects, and Orthopedic Screws

A Phantom Study

Jakob Neubauer, MD, Matthias Benndorf, MD, Hannah Lang, MD, Florian Lampert, MD, Lars Kemna, MD, Lukas Konstantinidis, MD, Claudia Neubauer, MD, Kilian Reising, MD, Horst Zajonc, MD, Elmar Kotter, MD, Mathias Langer, MD, and Sebastian M. Goerke, MD

Abstract: To compare the visualization of cortical fractures, cortical defects, and orthopedic screws in a dedicated extremity flat-panel computed tomography (FPCT) scanner and a multidetector computed tomography (MDCT) scanner.

We used feet of European roe deer as phantoms for cortical fractures, cortical defects, and implanted orthopedic screws. FPCT and MDCT scans were performed with equivalent dose settings. Six observers rated the scans according to number of fragments, size of defects, size of defects opposite orthopedic screws, and the length of different screws. The image quality regarding depiction of the cortical bone was assessed. The gold standard (real number of fragments) was evaluated by autopsy.

The correlation of reader assessment of fragments, cortical defects, and screws with the gold standard was similar for FPCT and MDCT. Three readers rated the subjective image quality of the MDCT to be higher, whereas the others showed no preferences.

Although the image quality was rated higher in the MDCT than in the FPCT by 3 out of 6 observers, both modalities proved to be comparable regarding the visualization of cortical fractures, cortical defects, and orthopedic screws and of use to musculoskeletal radiology regarding fracture detection and postsurgical evaluation in our experimental setting.

(*Medicine* 94(31):e1231)

Abbreviations: CT = computed tomography, DICOM = digital imaging and communications in medicine, FPCT = flat-panel computed tomography, MDCT = multidetector computed tomography, PACS = picture archiving and communication system.

Editor: Oguzhan Ekizoglu.

Received: February 13, 2015; revised: April 15, 2015; accepted: July 6, 2015.

From the Department of Radiology (JN, MB, HL, LK, CN, EK, ML); Department of Plastic and Hand Surgery (FL, HZ, SMG); and Department of Orthopedics and Traumatology, University Hospital Freiburg, Freiburg, Germany (LK, KR).

Correspondence: Jakob Neubauer, University Medical Center Freiburg, Freiburg, Baden-Württemberg, Germany (e-mail: jakob.neubauer@uniklinik-freiburg.de)

The authors have no conflicts of interest to disclose.

Copyright © 2015 Wolters Kluwer Health, Inc. All rights reserved.

This is an open access article distributed under the Creative Commons Attribution-NonCommercial-NoDerivatives License 4.0, where it is permissible to download, share and reproduce the work in any medium, provided it is properly cited. The work cannot be changed in any way or used commercially.

ISSN: 0025-7974

DOI: 10.1097/MD.0000000000001231

INTRODUCTION

Mainly 2 different types of X-ray detectors are in use in today's medical computed tomography (CT) scanners: row detectors and flat-panel detectors. Row detectors were already used in the first clinical CT-scanners (EMI scanner), counting 2 columns of detector elements.¹

With introduction of spiral CT in the early 1990s, a new technology evolved, which made use of wider detector arrays to facilitate faster scanning.² Consecutively, the manufacturers started to build broader detectors with up to 320 rows and an increased z-coverage, known as multidetector CTs (MDCT).

Coming from the field of radiography and angiography, the flat-panel detector, on the other hand, provided larger dimensions and hence a higher volume coverage to begin with. Flat-panel CTs (FPCT) work without helical movement and perform a number of angulated projections, which are taken to reconstruct a three-dimensional dataset.³

The 2 different detector systems show relevant differences in their generated images. It was found that MDCT has a higher contrast resolution, produces fewer image artifacts, and has a lower scan time.^{4,5} Nonetheless, the FPCT provides a higher spatial resolution.

This could be advantageous in musculoskeletal radiology with the need of visualizing detailed anatomical structures, especially for fracture recognition. Adequate accuracy for the imaging of the wrist has previously been described for different FPCT systems.^{6,7} FPCT also is described to be a promising method for arthrography of the wrist.^{8,9}

Hence, the aim of this study was to evaluate whether the visualization and consecutively the detection of nondislocated fractures and cortical defects is advantageous in FPCT compared with MDCT. We also investigate the visualization of orthopedic screws and their effect on measurements of opposing cortical defects and the image quality of both modalities referring to depiction of cortical bone.

METHODS

Phantoms

We developed a phantom system with feet of adult *Capreolus capreolus* (European roe deer). The synostosed 3rd and 4th metatarsal bones of these feet have a similar diameter to human metatarsal bones and therefore yield comparability to the human body. The feet were taken from abattoir refuse. Thus, an approval from our institutions ethics committee was not required. Altogether, we used 21 feet for our study.

Phantom Preparation

Fracture Phantom

The synostosed 3rd and 4th metatarsal bones of 18 phantoms were fractured with a universal testing machine (UTS 20/testControl, UTS Systems, Ulm, Germany; software: TestXpert II, Zwick, Ulm) using compression and a 3-point bending load. Force transmission was carried out with a 5 × 5 cm metal plate and a velocity of 400 mm/min. Force transmission was stopped at the sudden loss of 90% of the maximal force introduced (fracture detection). Figure 1 illustrates the phantom preparation.

Cortical Defect and Orthopedic Screw Phantom

Another 3 synostosed metatarsal bones were prepared with cortical defects, orthopedic screws, or both combined (Figure 1C and D). For this purpose, the feet were partially skinned. To the first synostosed metatarsal bone 10 round cortical defects were applied with orthopedic wires of different strengths, ranging from 0.6 to 2 mm in increments of 0.2 mm (Stryker, Kalamazoo, MI). Wires with the strength of 1 and 2 mm were used to apply 2 cortical defects each. The cortical defects were applied in a random order.

The second synostosed metatarsal bone was equipped with 10 orthopedic titanium screws of 10 mm length (Stryker) and cortical defects on the opposite side that were applied as reported for the first foot but in different order (Figure 2).

In the third synostosed metatarsal bone 10 orthopedic titanium screws of different lengths were installed, ranging from 6 to 11 mm in steps of 1 and 0.5 mm (Stryker). The order was randomly chosen as well.

After preparation of the synostosed metatarsal bones the situs was filled up with water to press out all air and a cutaneous suture was applied. All phantoms were crafted by 3 hand surgeons with 3, 5, and 20-years experience in surgery.

CT Examinations

CT examinations were performed in a mobile compact FPCT (Verity, Planmed Oy, Helsinki, Finland) and an MDCT (Aquilion One, Toshiba, Minato, Japan). Dose measurements

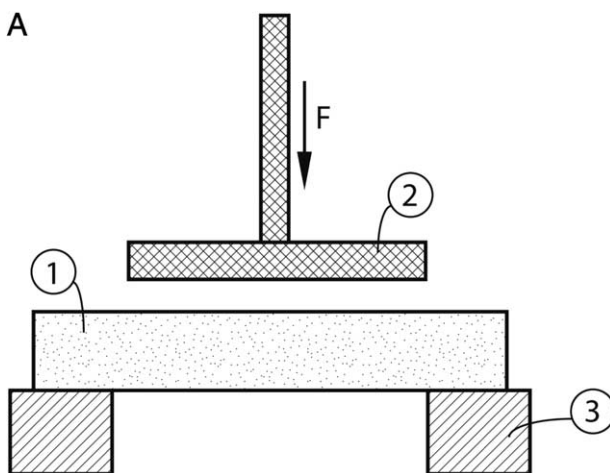


FIGURE 1. Schematic illustration of the fracturing setup in the universal testing machine with 1 being the deer foot, 2 being the metal plate, and 3 being a base on which the deer foot is positioned. The arrow is indicating the direction of force.

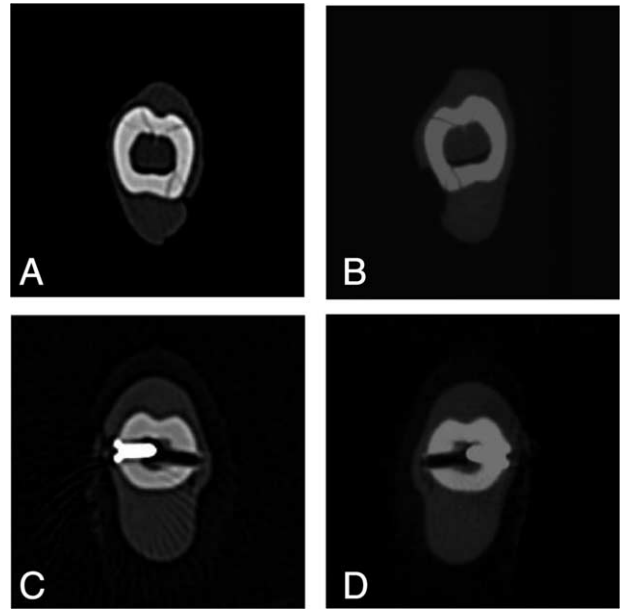


FIGURE 2. Example images of the fracture phantom (A, B) and the cortical defect/orthopedic screw phantom (C, D) in the MDCT (A, C) and FPCT (B, D).

were performed as previously published.⁴ Examinations in the FPCT were performed with default settings. Field of view (FOV) and dose settings of the MDCT were adjusted to meet the properties of its counterpart (Table 1). The FPCT performed a partial rotation of 210°, while acquiring 300 projection images. The MDCT performed a partial rotation of 180° without pitch. The same CT table was used in both devices. The synostosed 3rd and 4th metatarsal bones of all prepared phantoms were scanned. Image reconstructions were performed with default settings in each device following manufacturer’s instructions. MDCT images were reconstructed using iterative technique (AIDR3), and FPCT images were calculated with a filtered back projection algorithm. Image data were sent to a picture archiving and communication system (PACS/ AGFA Impax 6, Agfa, Mortsel, Belgium).

Gold Standard

Fracture Phantom

After image acquisition the fractured feet were boiled for 30 min, carefully anatomized and fracture fragments were counted. The fragment count ranged from 1 to 23 with

TABLE 1. Scan Protocols for FPCT and MDCT

| | FPCT | MDCT |
|-----------------------------|-----------------|-------------------|
| Field of view | 16 × 16 × 13 cm | 16 × 16 × 12.8 cm |
| Matrix | 801 × 801 pixel | 512 × 512 pixel |
| Slice thickness and spacing | 0.2 mm | 0.2 mm |
| KVp | 90 | 100 |
| mAs | 36 | 22 |
| mGy | 7.20 ± 0.16 | 7.26 ± 0.17 |

FPCT = flat-panel computed tomography; MDCT = multidetector computed tomography.

1 synostosed metatarsal bone being intact. The mean fragment count was 13.17 with a standard deviation of ± 6.56 .

Cortical Defect and Orthopedic Screw Phantom

The strength of the orthopedic wires as given by the vendor was taken as the true diameter of the cortical defects. Equally, the length of the screws as given by the vendor was taken as the true value.

Image Analysis

Six readers (2 radiologists with 25 and 2 years of experience in musculoskeletal radiology, 2 orthopedic surgeons with 12 and 7 years experience in musculoskeletal radiology, and 2 hand surgeons with 5 and 3 years experience in musculoskeletal radiology) performed a quantitative and qualitative image analysis. Images were evaluated in a PACS (AGFA Impax 6, Agfa, Mortsels, Belgium), viewing conditions were kept constant and the displays used (RadiForce RX220; EIZO Corp, Hakusan, Ishikawa, Japan) were calibrated according to digital imaging and communications in medicine (DICOM) part 14.¹⁰

The readers were blinded to the modality of the scans. The scans were presented in a randomized order with a randomized alteration of MDCT and FPCT image series. To avoid recall bias, the equivalent images of the other modality were presented to the readers in a mirrored way in different randomized order after 8 weeks.

Quantitative Data Analysis

The number of fragments was counted in the fractured deer feet. The diameter of cortical defects and the length of screws were measured.

Qualitative Data Analysis

Subjective image quality relating to the depiction of the cortical bone was rated by each observer in each scan using a Likert scale with the scores 1 (= very good), 2 (= good), 3 (= fair), 4 (= poor), and 5 (= very poor).

Statistical Analysis

The readers' fragment counts and measurements were compared for accuracy regarding the gold standard using the Pearson product-moment correlation coefficient, mean values are stated.

We defined inter-rater agreement as the agreement of readers' counts and measurements in 1 modality. To test the overall inter-rater agreement between the 6 readers for their counts and measurements, Kendall W was employed. To determine the single inter-rater agreements, exhaustive correlation matrices were generated using the Pearson product-moment correlation coefficient.

We defined interdevice agreement as the agreement of 1 reader's counts and measurements in both modalities. To determine the interdevice agreement, correlation was evaluated using Pearson product-moment correlation coefficient, values were plotted and univariate linear regression models were generated; a slope of 1 and intercept of 0 would denote perfect agreement. A level of correlation from 0 to 0.2 was regarded as very poor, from 0.21 to 0.4 as poor, from 0.41 to 0.6 as moderate, from 0.61 to 0.8 as good, and from 0.81 to 1 as very good.

The readers' evaluations of image quality for both modalities were compared using the Wilcoxon signed-rank test. An

alpha level of 0.05 was considered to denote statistical significance. To account for possible alpha-error accumulation in the readers' evaluations, a Bonferroni correction was applied with an adjusted alpha level of 0.008.¹¹ Statistical analysis was performed with R (Version 3.0.3).

RESULTS

Quantitative Analysis

The number of cortical fragments ranged from 1 to 27. The readers had a mean correlation of their fragment counts with the gold standard of 0.61 for both devices ($P > 0.99$). The inter-device correlation ranged from 0.31 to 0.86 (Figure 3).

There was an overall inter-rater correlation regarding the fragment count of 0.67 for the MDCT and 0.62 for the FPCT with P -values of < 0.001 . By analyzing the single inter-rater correlations, we found obvious differences between devices only for observer 4 (Figure 4).

The measurements of cortical defects ranged from 0.6 to 2 mm in the MDCT and from 0.5 to 2.5 mm in the FPCT (Figure 5). The mean correlations of the measured cortical defects with the gold standard were 0.93 for the MDCT and 0.96 for the FPCT without a significant statistical difference ($P = 0.48$). The inter-device correlations of measured cortical defects ranged from 0.72 to 0.96 (Figure 5). There was an overall inter-rater correlation for cortical defects with 0.92 in the MDCT and 0.96 in the FPCT with P -values < 0.001 .

For the phantom that also had screws on the opposite side, correlations of measurements of cortical defects with the gold standard were 0.97 for the MDCT and 0.98 for the FPCT with no significant difference ($P = 0.7$). The overall inter-rater correlation was equally significant for both, MDCT and FPCT, with 0.96 and P -values < 0.001 . The inter-device correlation was 0.92–0.98 for this experimental setting (Figure 6).

The measurements of screws ranged from 5.4 to 11.6 mm in the MDCT (Figure 6A) and 5.5 to 14 mm in the FPCT (Figure 7). We found overall inter-rater correlation for measurements of the length of screws with 0.95 ($P < 0.001$) in both modalities. The mean correlation values for screw measurement with the gold standard were 0.97 for MDCT and 0.96 for FPCT. The inter-device correlation ranged from 0.93 to 0.99.

Qualitative Analysis

The mean ratings of image quality on a Likert scale ranging from 1 (= very good) to 5 (= very poor) were 2.54 for MDCT and 3.04 for FPCT. Observers 2, 5, and 6 rated the MDCT better, whereas the ratings of observers 1, 3, and 4 showed no significant preference (Table 2).

DISCUSSION

In our study, we demonstrate that observer performance in fracture detection is comparable between FPCT and MDCT in our experimental setting of artificially fractured deer feet.

We also show that observer measurements are equally exact on depicted orthopedic screws and cortical defects in both modalities, even if the latter are in direct vicinity to osteosynthetic material. Furthermore, we demonstrate that the half of the observers rate the image quality of MDCT superior compared with FPCT for the depiction of cortical bone structures.

A comparable performance regarding the detection of nondislocated fractures gives evidence that FPCT, as an emerging technique in trauma imaging^{7,12}, may be a viable alternative to MDCT in this setting. The differences in spatial

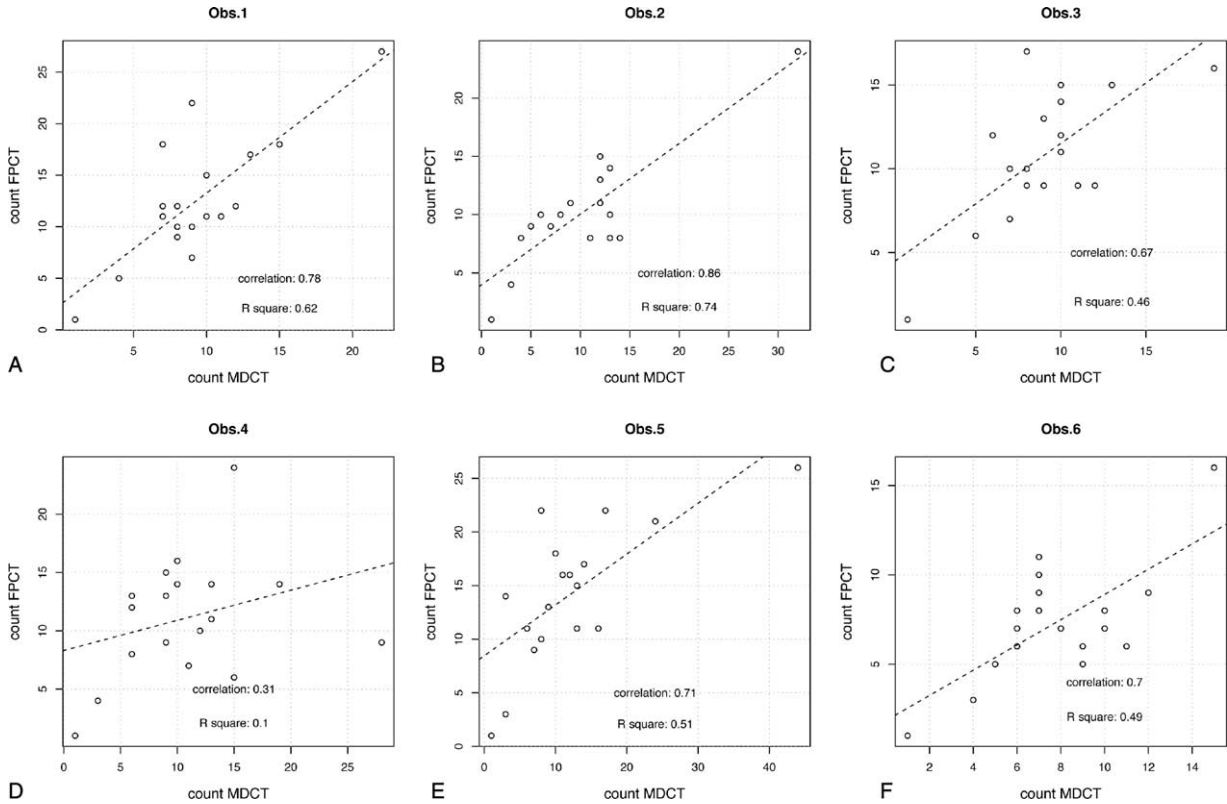


FIGURE 3. Interdevice agreement for each of the 6 observers (A–F each presenting 1 single observer) referring to fracture fragment count.

resolution between the MDCT and the FPCT are probably too small to result in relevant differences in the detection of fractures. In addition, the different reconstruction algorithms of both scanners will have influenced the results to some extent.

Namely, the iterative reconstruction technique that is used in the MDCT device is known to reduce image noise without altering the spatial resolution.¹³ The images of the FPCT, on the other hand, are reconstructed with a filtered back projection algorithm.

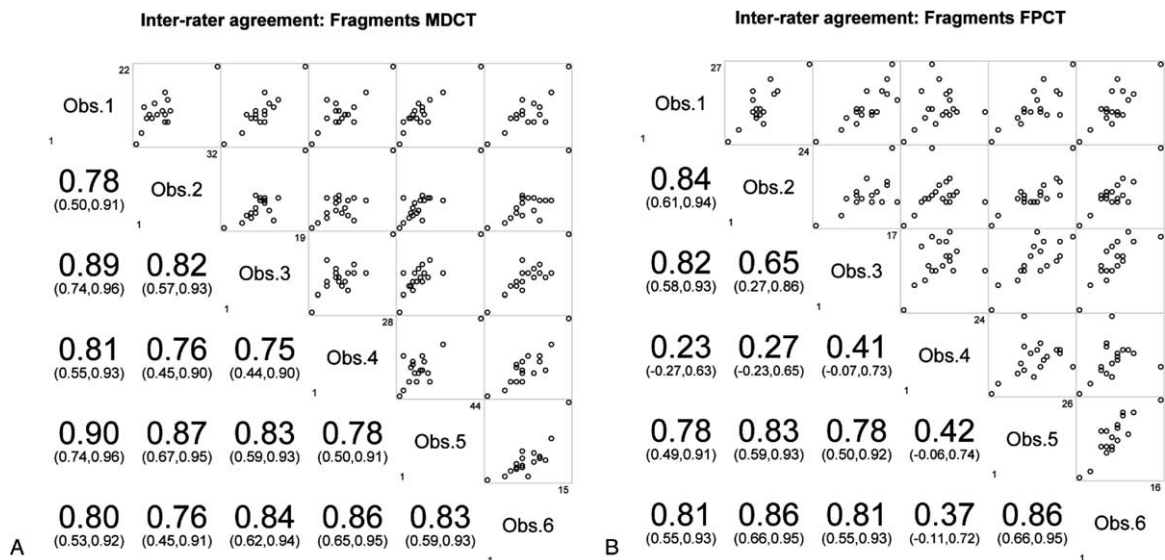


FIGURE 4. Inter-rater agreement for all observers in MDCT (A) and FPCT (B) referring to fracture fragment count. The lower panel indicates the Pearson product-moment correlation coefficient and the upper panel shows the scatterplot of each inter-rater combination.

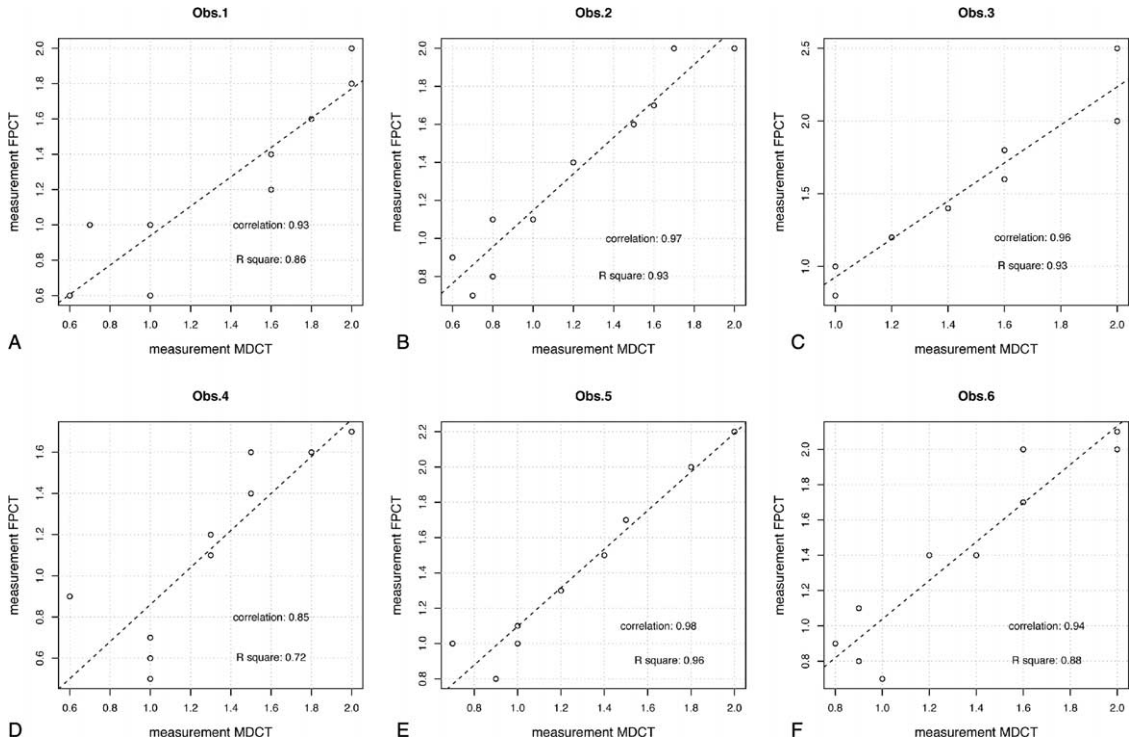


FIGURE 5. Interdevice agreement for all 6 observers (A–F) referring to measurements of cortical defects without opposing orthopedic screws.

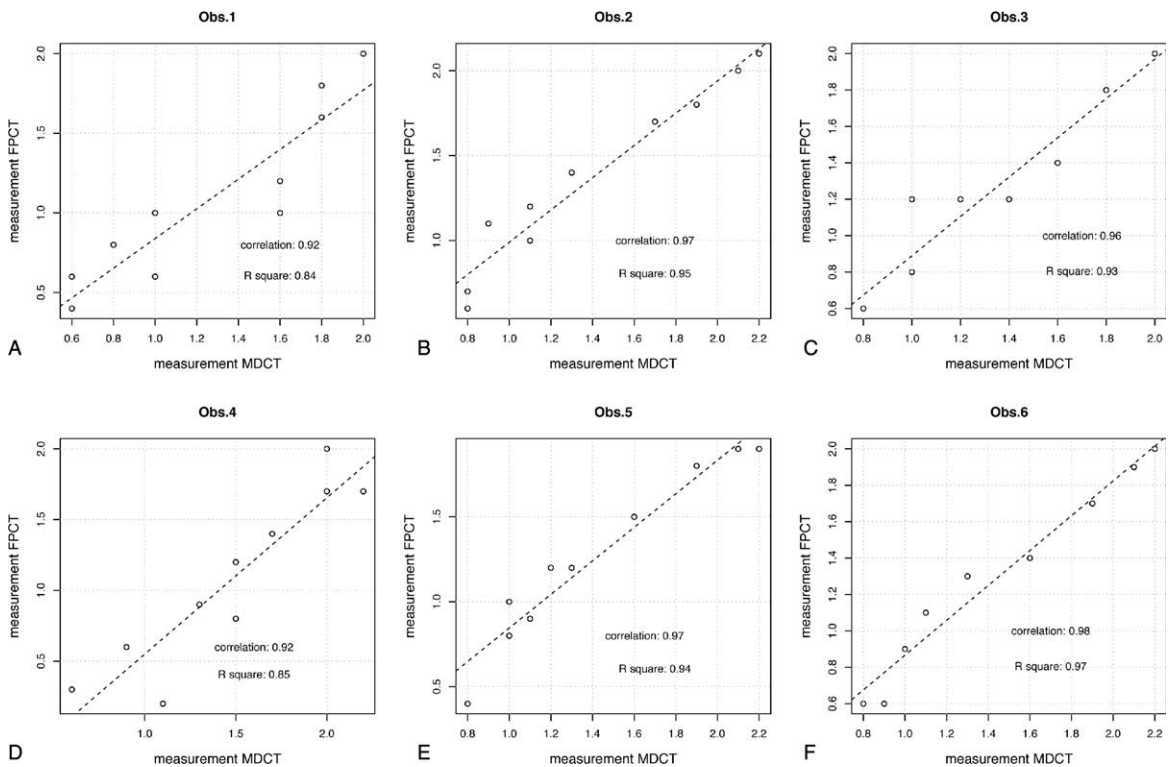


FIGURE 6. Interdevice agreement for all observers (A–F) referring to measurements of cortical defects of the phantom with opposing orthopedic screws.

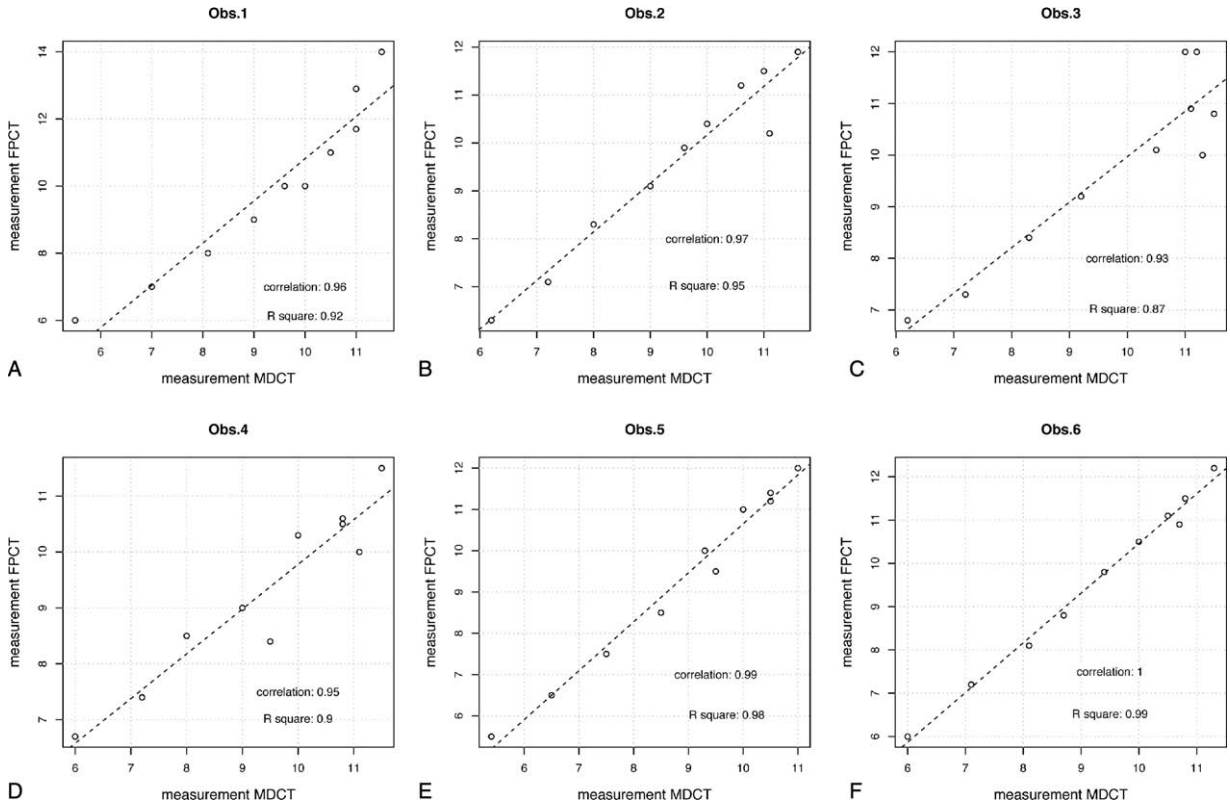


FIGURE 7. Interdevice agreement for all observers (A–F) referring to measurements of orthopedic screws.

The inter-rater correlations in our study relating to fragment count showed slightly higher values for the MDCT, which can be attributed to the performance of a single observer (No. 4) rather than representing an overall trend. This hypothesis is supported by the fact that the fragment count in both modalities shows a good mean correlation with the gold standard with no significant difference.

Also, the equal performance in the evaluation of orthopedic screws and cortical defects makes the FPCT a candidate for postsurgical musculoskeletal imaging.

Three out of 6 observers, the experienced orthopedic surgeon and both radiologists rated the subjective image quality for depiction of cortical bone higher in the MDCT than in the

FPCT. The other 3 observers showed no preferences. From our point of view, this can primarily be attributed to the iterative reconstruction technique, which produces more favorable images due to noise reduction.¹⁴ It could also follow from the longer experience the raters had with the MDCT and its image characteristics that they are more used to.

The main advantage of the FPCT is thought to be the higher spatial resolution, leading to a more exact representation, especially of the bony structures.^{9,15,16} Thus, it might be assumed that the potentially higher spatial resolution could lead to a superior observer performance in fracture detection. Nevertheless, image quality does not solely depend on spatial resolution but is also influenced by contrast resolution, noise,

TABLE 2. Mean Ratings of Image Quality Referring to Depiction of Cortical Bone in MDCT and FPCT for Each Observer (Obs. 1–6)

| Observer Number, Specialization, and Years of Experience | MDCT (Mean) | FPCT (Mean) | P Value |
|--|-------------|-------------|---------|
| Obs. 1 (hand surgeon, 3 yrs) | 2.23 | 2.86 | 0.01 |
| Obs. 2 (radiologist, 25 yrs) | 2.68 | 3.55 | 0.004* |
| Obs. 3 (orthopedic surgeon, 7 yrs) | 2.95 | 3.05 | 0.97 |
| Obs. 4 (hand surgeon, 5 yrs) | 2.91 | 3.05 | 0.35 |
| Obs. 5 (radiologist, 2 yrs) | 2.41 | 3.50 | <0.001* |
| Obs. 6 (orthopedic surgeon, 12 yrs) | 2.05 | 2.73 | 0.004* |

The asterisk indicates statistical significance with Bonferroni’s correction being applied. FPCT = flat-panel computed tomography; MDCT = multidetector computed tomography.

and artifacts.³ These image properties are highly contingent on the hard- and software of CT scanners, whose incompatible designs often hamper comparability.

Faccioli et al found the FPCT to perform slightly inferior to the MDCT in detection of bone fragments in finger fractures.¹² It is to be noted that in this study the radiation dose of the MDCT was comparably higher and the MDCT was chosen as gold standard.

In our study, we adjusted every scan parameter possible to facilitate a good foundation for equation, even applying the same radiation dose for scans in both devices. Additionally, our experimental design has 1 major advantage. Our gold standard was established with exact anatomical matching, which is not feasible in clinical studies of nondislocated extremity fractures. Compared with this gold standard we see the FPCT and MDCT performing equally well in detection of fractures.

From a technical point of view, FPCT imaging should result in more artifacts than MDCT imaging because of the technical set-up and a higher amount of scatter radiation.¹⁷ Consecutively, the majority of papers reports more artifacts in FPCT compared with MDCT,^{4,5,18} although few data suggest different results.^{19,20} These diverging results can probably be explained due to differences in density, configuration, and positioning of the tested material.

Regarding the measurement of orthopedic screws, which is highly dependent on the presence/absence of artifacts we found in our study that both modalities enable precise measuring of these metallic items. Also, we found excellent inter-rater correlation for the MDCT and FPCT. Thus, we could not detect relevant differences in arti-fact-related observer performance between the 2 CT scanners and both seem to be suited for and postoperative musculoskeletal imaging.

Although the better spatial resolution of FPCT obviously does not lead to a higher detection of cortical fractures in our experimental setting, the method still yields comparable results to MDCT. Thus, FPCT may be an alternative to MDCT regarding pre- and postoperative musculoskeletal extremity imaging. Besides, the technical setup of the FPCT is simpler compared with MDCT.^{6,21,22} This could potentially lead to easier patient positioning and lower costs, resulting in patient and economic healthcare benefits. However, these issues should be further investigated in future studies.

Limitations

Our comparison is restricted to a certain pair of scanners. Besides, we had to use different reconstruction algorithms in both modalities because of the system architecture. We analyzed static feet phantoms in the scanners but not the vulnerability of the scanners to motion artifacts.

CONCLUSION

Although the subjective image quality was rated higher in the MDCT than in the FPCT by 3 out of 6 observers, no relevant differences were detected between both modalities concerning fracture detection, measurement of small cortical defects, and orthopedic screws or the detection of cortical defects near orthopedic material. Thus, both modalities proved to be comparable regarding the visualization of cortical fractures, cortical defects, and orthopedic screws and of use to musculoskeletal radiology regarding fracture detection and postsurgical evaluation in our experimental, dose equivalent setting. Further studies are needed to confirm these preclinical data.

ACKNOWLEDGMENT

We would like to sincerely thank Johannes M. Voigt and Martin Fiebich for their help regarding dose measurements. The article processing charge was funded by the German Research Foundation (DFG) and the Albert Ludwigs University Freiburg in the funding programme Open Access Publishing.

REFERENCES

1. New PF, Scott WR, Schnur JA, et al. Computerized axial tomography with the EMI scanner. *Radiology*. 1974;110:109–123.
2. Kalender WA. X-ray computed tomography. *Phys Med Biol*. 2006;51:R29–R43.
3. Kalender WA, Kyriakou Y. Flat-detector computed tomography (FD-CT). *Eur Radiol*. 2007;17:2767–2779.
4. Neubauer J, Voigt JM, Lang H, et al. Comparing the image quality of a mobile flat-panel computed tomography and a multidetector computed tomography: a phantom study. *Investig Radiol*. 2014;49:491–497.
5. Finkstaedt T, Morsbach F, Calcagni M, et al. Metallic artifacts from internal scaphoid fracture fixation screws: comparison between c-arm flat-panel, cone-beam, and multidetector computed tomography. *Investig Radiol*. 2014;49:532–539.
6. Zbijewski W, Jean PD, Prakash P, et al. A dedicated cone-beam CT system for musculoskeletal extremities imaging: design, optimization, and initial performance characterization. *Med Phys*. 2011;38:4700–4713.
7. De Cock J, Mermuys K, Goubau J, et al. Cone-beam computed tomography: a new low dose, high resolution imaging technique of the wrist, presentation of three cases with technique. *Skelet Radiol*. 2012;41:93–96.
8. Ramdhan-Wihlm R, Le Minor J-M, Schmittbuhl M, et al. Cone-beam computed tomography arthrography: an innovative modality for the evaluation of wrist ligament and cartilage injuries. *Skelet Radiol*. 2012;41:963–969.
9. Guggenberger R, Winklhofer S, Spiczak JV, et al. In vitro high-resolution flat-panel computed tomographic arthrography for artificial cartilage defect detection: comparison with multidetector computed tomography. *Investig Radiol*. 2013;48:614–621.
10. DICOM Part 14. 2011. http://medical.nema.org/Dicom/2011/11_14pu.pdf. Accessed: February 12, 2015.
11. Bland JM, Altman DG. Multiple significance tests: the Bonferroni method. *BMJ*. 1995;310:170.
12. Faccioli N, Foti G, Barillari M, et al. Finger fractures imaging: accuracy of cone-beam computed tomography and multislice computed tomography. *Skelet Radiol*. 2010;39:1087–1095.
13. Gervaise A, Osemont B, Lecocq S, et al. CT image quality improvement using adaptive iterative dose reduction with wide-volume acquisition on 320-detector CT. *Eur Radiol*. 2012;22:295–301.
14. Singh S, Kalra MK, Hsieh J, et al. Abdominal CT: comparison of adaptive statistical iterative and filtered back projection reconstruction techniques. *Radiology*. 2010;257:373–383.
15. Bredella MA, Misra M, Miller KK, et al. Distal radius in adolescent girls with anorexia nervosa: trabecular structure analysis with high-resolution flat-panel volume CT. *Radiology*. 2008;249:938–946.
16. Damet J, Sans-Merce M, Miéville F, et al. Comparison of organ doses and image quality between CT and flat panel XperCT scans in wrist and inner ear examinations. *Radiat Prot Dosim*. 2010;139:164–168.

17. Schulze R, Heil U, Gross D, et al. Artefacts in CBCT: a review. *Dento Maxillo Facial Radiol.* 2011;40:265–273.
18. Draenert FG, Coppentrath E, Herzog P, et al. Beam hardening artefacts occur in dental implant scans with the NewTom cone beam CT but not with the dental 4-row multidetector CT. *Dento Maxillo Facial Radiol.* 2007;36:198–203.
19. Stuehmer C, Essig H, Bormann K-H, et al. Cone beam CT imaging of airgun injuries to the craniomaxillofacial region. *Int J Oral Maxillofac Surg.* 2008;37:903–906.
20. Pauwels R, Stamatakis H, Bosmans H, et al. Quantification of metal artifacts on cone beam computed tomography images. *Clin Oral Implant Res.* 2013;24:94–99.
21. Kalender WA. The use of flat-panel detectors for CT imaging. *Der Radiol.* 2003;43:379–387.
22. Kyriakou Y, Kolditz D, Langner O, et al. Digital volume tomography (DVT) and multislice spiral CT (MSCT): an objective examination of dose and image quality. *RöFo.* 2011;183:144–153.