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Original article

Comparison of intraoperative flat panel imaging and postoperative plain radiography for the detection of intraarticular screw displacement in volar distal radius plate ostheosynthesis

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ABSTRACT

Objectives: To investigate if intraoperative 3D flat panel imaging improves the detection of radiocarpal intraarticular screw misplacement (RCSM) in comparison to standard postoperative x-ray.
Methods: In a study on cadaver specimens, we evaluated the sensitivity and specificity to detect RCSM using X-ray, intraoperative 3D-fluoroscopy as well as the digital volume tomography. The gold standard reference was computed tomography.
Results: Sensitivity for the detection of RCSM for X-ray was 58% and specificity 88%. For DVT, the sensitivity to detect RCSM was 88% and the specificity 53%. For 3D-fluoroscopy, the sensitivity for RCSM was 68% and specificity 95%. When combining the methods, the best performance was found, when combining the two intraoperative imaging methods, with a resulting sensitivity of 88% and a specificity of 73%.
Conclusions: Intraoperative 3D fluoroscopy and digital volume tomography appear to be at least as sensitive and specific to detect RCSM than the regular postoperative radiography in two planes. However, especially discrete screw misplacements can be missed with either method.
Level of evidence: Level IV. Diagnostic device study.

1. Introduction

Fractures of the distal radius account for more than 15% of fractures seen in the emergency room. The prevalence of intraarticular distal radius fractures accounts to approximately 60% of all radius fractures [1,2]. For good clinical outcome of distal radius fractures (DRF), the correct anatomic reduction of the joint surface is crucial [3–5]. In order to obtain good results in periarticular implantation of plate osteosynthesis at the distal radius, the screw placement close to the subperiosteal lamella is recommended in order to provide optimal stability of the cortical joint surface [6,7]. However, the correct extraarticular screw placement is difficult to assess with projectional radiography due to the three-dimensional concave articular surface of the distal radius in the radiocarpal joint with the overlying projection of the ulnar and radial styloid processus and possible metal artefacts [8–10]. For the fractured radius, marginal irregularities of the joint surface, as well as intraarticular screw placements are associated with severe chondromalacia [4,11]. Although the complication is severe and likely to occur, the reported prevalence of radiocarpal screw misplacement (RCSM) is very low, compared to the prevalence of postoperative pain syndroms [12–14]. The complication of x-ray detected RCSM is being associated to < 1% of cases and approximately 5% of cases in which implants need to be removed [12,15]. It remains unclear whether the existing study data reflects the true rate of RCSM.

In order to improve the detection of RCSM as well as possible failure in reconstruction of the joint surface, the early detection of intraarticular screw misplacement and periarticular cortical screw penetration during the surgical procedure appears to be a promising strategy. New technologies have been developed that aim to solve this problem in the surgery room, allowing

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intraoperative 3D-fluoroscopy (e.g. CineView®) and 3D C-arm digital volume tomography (DVT) to be performed. These methods offer additional qualities to the conventionally and widely used intraoperative fluoroscopy, the plain radiography as well as the option of a post-procedural computed tomography (CT) [15]. However, the opportunity to achieve an improvement in patient care with additional imaging modalities must be counterbalanced with the risk of repeated and imprudent exposure to methods using radiation, as well as additional false positive or false negative findings. With the hypothesis that state of the art intraoperative flat panel imaging is as good as the postoperative computed tomography (CT) for depicting intraarticular screw placement, we compared conventional postoperative two plain radiography with intraoperative 3-D fluoroscopy and DVT for the detection of RCSM. For this purpose, we chose an ex vivo approach to compare the sensitivity and specificity of the indicated imaging modalities, with computed tomography serving as the reference standard.

2. Materials and methods

2.1. Specimens and surgical procedures

Twelve human cadaver specimens of the forearm were used for this study. Approval was obtained from the local ethic commission. An oscillating saw was used to create a coronal and a sagittal osteotomy in order to imitate a complete intraarticular distal radius fracture (AO 23-C.1). Following osteotomy, a standard distal radius T-plate (2.4 distal radius locking compression plate [LCP], Synthes, Umkirch, Germany) was used to stabilize the fracture in a surgical procedure. Three or four screws were placed into the distal fragment and two screws were placed into the shaft. During reduction and placement of the implant, standard fluoroscopy (Ziehm, Expo 8000, Erlangen, Germany) was used to determine correct positioning in anteroposterior and lateral position, as frequently performed. After reaching sufficient reduction and plate positioning, the screws were inserted according to the standard method using a length gauge.

2.2. Imaging techniques

After reduction and screw placement, plain radiographs were taken as postoperative control study in standard sagittal and anteroposterior planes (50 kV, 10 mA, digital image acquisition with shutter priority, dose of approximately 50–100 μSv). Next, a three-dimensional fluoroscopy was performed with the digital flat panel detector (Ziehm Vision FD Vario 3D, Nuremberg, Germany). For this purpose, the specimen was positioned as in the clinical routine, palmar side up, on an acrylic glass table according to the manufacturer instruction (110 images, 50 kV, 10 mA, 90° rotation, dose of approximately 30–50 μSv) (Fig. 1). The data acquisition was completed within approximately three minutes and images were reconstructed in axial, coronal, and sagittal planes for evaluation. While the post-processing took around 1 minute of time, the software calculated a so-called cine mode of approximately 110 images. The images that constitute the 3D-fluoroscopy (Cine-view) were separately stored. The DVT reconstruction was performed based on the 3D-fluoroscopy data, providing a stack of 500 images with slice thickness of 0.25 mm (Fig. 2).

After the procedure, a high resolution CT scan was performed on a 64-row CT scanner (Somatom Sensation 64, Siemens, Erlangen, Germany) (Fig. 3). The scan was performed according to the protocol for the distal forearm that is used in our department in clinical routine. The high resolution protocol with 1-mm slice thickness, 120 mAs, 120 kV, a rotation-time of 0,5 sec, Kernel B70s and an effective dose of 1–1.5 mSv allowed 3D multiplanar reconstructions that were used for the determination of the gold-standard reference. Standard clinical procedures of image post-processing were applied.

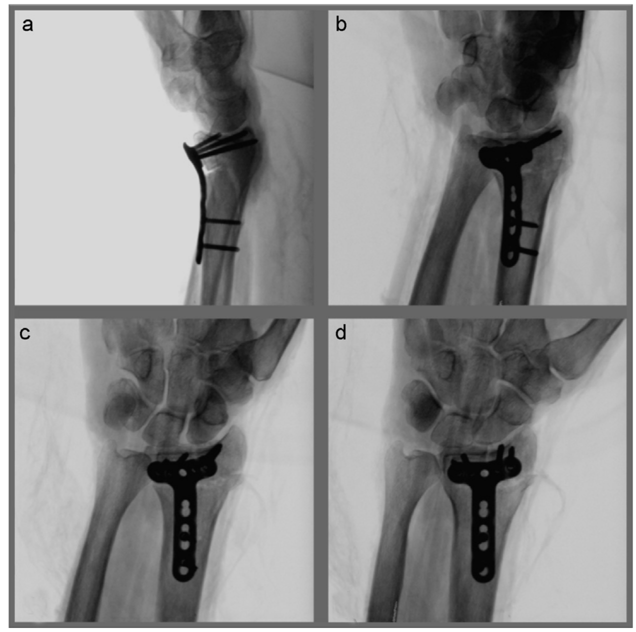

Fig. 1. a–d: four 3D-fluoroscopy images of a series of 110 images, showing distal radius LCP osteosynthesis. The image quality was rated to be very good. In this case, intraarticular screw cutting out of the medial radial screw (arrow) was suspected in X-ray. The oblique projections helped to identify the extraarticular screw position that was confirmed with computed tomography.

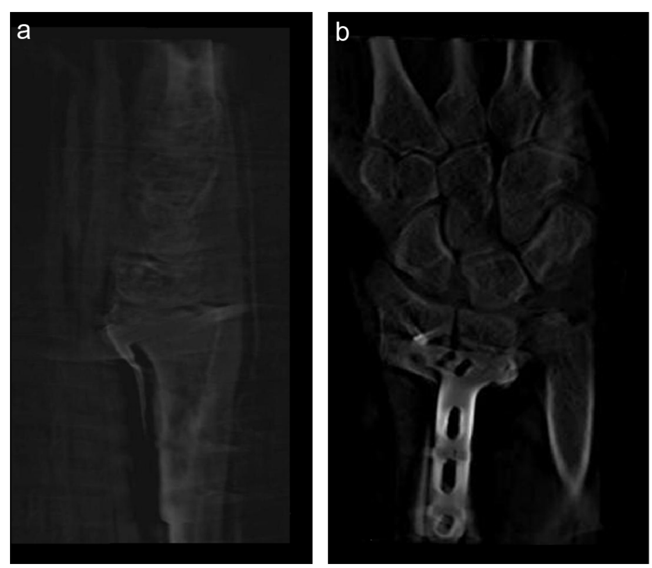

Fig. 2. a and b: two reconstructed image examples of a 3D DVT dataset, showing LCP osteosynthesis at the distal radius. In opposite to 3D-fluoroscopy and X-ray, the image quality of the DVT datasets, that was acquired with 50–100 μSv, was rated "low" due to the beam hardening artefacts as well as low contrast of the joint surface in the reconstructed images (Fig. 3a). However, the 3D DVT showed a higher sensitivity for the detection of intraarticular screw cutting out than X-ray and 3D fluoroscopy.

2.3. Image and data evaluation

The image evaluation of all studies was performed in consensus by a specialist orthopaedic surgeon (8 years of professional experience) and a specialist radiologist (10 years of professional

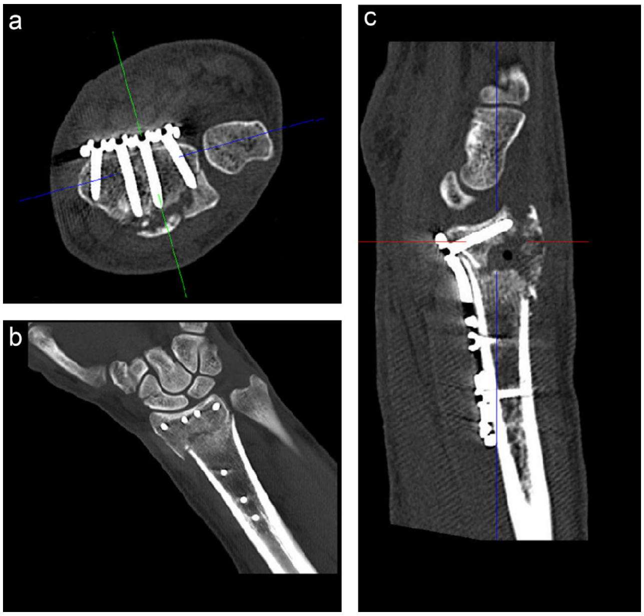

Fig. 3. a–c: CT imaging of LCP plate osteosynthesis at the distal radius. CT served as the gold standard of the study. The 3D-angulation allows exact location of every screw-up to the screw-tip without disturbing artefacts.

experience). Both observers were not involved in specimen preparation, data acquisition and data post-processing. In random order, plain fluoroscopic control images, the 3D-fluoroscopy sequence, DVT and reconstructions of a CT scan were evaluated. The datasets were randomly chosen from the 12 specimens. To avoid recognition-effects, the evaluation of radiographs, fluoroscopy, DVT and CT took place after a 1-week interval between the evaluations of each modality. For each set of data consensus was obtained and documented in a digital dialogue for the following parameters:

- intra- or extraarticular screw position (0: extraarticular screw placement; 1: marginal intraarticular screw placement overlapping the cortical bone surface less than 2 mm; 2: screw overlapping the cortical bone surface substantially, more than 2 mm);
- plate positioning (1: correct; 2: acceptable; 3: incorrect);
- the quality of fracture reduction (1: sufficient; 2: fracture gaps too large);
- estimated reliability of the observation (1: good; 2: acceptable; 3: unacceptable);
- the subjective image quality (1: good; 2: acceptable; 3: poor).

For the determination of the overall subjective image quality, the rating was considered to be good with a mean value of the scores (1–3) of up to 1,5, and poor with a mean value of greater 2,5. The determination of screw positioning for the combination of modalities was simulated a posteriori based on the results of the single modalities, taking into account the confidence level on extra- or intraarticular screw position that was stated by the radiologist for the single modalities (confidence level 1,2 or 3). In the case of diverging opinion on screw position between the results acquired for the single modalities, the rating with the higher confidence was assumed as the resulting opinion of the radiologist. In relation to the CT standard, the true positive (TP), false positive (FP), true negative (TN) and false negative (FN) cases were listed for X-ray, DVT and 3D-fluoroscopy. Based on these results, the specificity and sensitivity for RCSM were calculated in relation to results of the CT scan (specificity = [TN/(TN + FP)], sensitivity = [TP/(TP + FN)]). Jmp 7 software was used for this statistical data evaluation (SAS Institute Inc., Cary, NC, USA).

3. Results

A subjective quality rating of each scan and all image modalities was documented by the two investigators in consensus (data not shown). CT data, conventional X-ray and 3-D fluoroscopy were rated “good” in average. The 3D DVT (digital volume tomography) images and reconstructions were rated “poor” and much less informative as the other imaging modalities. There were no cases of material failure to be reported. For all specimens, fracture adaptation and plate positioning was rated “sufficient” by the radiologist as well as the surgeon, independent of imaging modality.

In the CT evaluation, the investigators were asked to exclude all screws if there was any uncertainty towards screw position, e.g. with a screw running along a joint surface or insecurity of definitive screw tip placement associated to minor artefacts. Due to quality assurance, 8 of 58 periarticular screws were excluded from the investigation. The remaining screws were rated “very good” with definite confidence in terms of screw placement.

The fraction of cases that were rated with high confidence by the investigators ranged between 66% (X-ray) and 78% (DVT) (Table 1). The overall fraction of correctly identified intraarticular screws was 39% for DVT, 43% for X-ray and 46% for 3D-fluoroscopy. For cases with high confidence, these results increased to in between 43% (DVT) – 53% (3D-fluoroscopy) (Table 1). The sensitivity and specificity was calculated for all modalities. Further, the sensitivity for the detection of marginal RCSM as reported by CT is provided (Table 2).

DVT showed the highest sensitivity of up to 88% for all cases and 67% for the detection of marginal RCSM as well as the lowest specificity of 53%, due to 8 false positive cases (Table 3). Four screws

Table 1
Sensitivity and specificity for the detection of intraarticular screw misplacement in the radiocarpal joint (RCSM), in relation to the gold standard computed tomography. Number of cases with correct positive, correct negative, false positive and false negative outcome.

	Correct positive	Correct negative	False positive	False negative	Sensitivity (%)	Specificity (%)
X-ray	11	15	2	8	58	88
DVT	15	9	8	2	88	53
3D-fluoroscopy	13	18	1	6	68	95
X-ray + 3D-fluoroscopy	18	13	2	6	75	88
X-ray + DVT	21	9	6	3	88	60
DVT + 3D-fluoroscopy	20	11	4	4	88	73
X-ray + DVT + 3D-fluoroscopy	21	9	6	3	88	60
Number of screws not evaluable						
X-ray	3					
DVT	5					
3D-fluoroscopy	1					

Table 2
Sensitivity for the detection of marginal intraarticular screw misplacement (RCSM ≤ 2 mm) into the radiocarpal joint, in relation to the gold standard computed tomography. Number of cases with correct positive and false positive outcome.

	Correct positive	False negative	Sensitivity (%)
X-ray	3	4	43
DVT	4	2	67
3D-fluoroscopy	2	5	29

Table 3
The fraction of cases that were rated to be evaluable with dedicated high confidence ($n = 50$).

X-ray	66%
DVT	78%
3D-fluoroscopy	67%

were not evaluable with DVT due to artefacts. 3D-fluoroscopy was most specific, reaching specificity in the detection of RCSM of 95%. The sensitivity towards RCSM was 68% overall but only 27% when there was a marginal RCSM to be reported. All X-ray images were regarded to be evaluable. However, in only 58% of the x-ray images, the investigators were confident that there was a correct extraarticular position of the screws. Sensitivity for RCSM detection by X-ray overall was 58%. Sensitivity of X-ray for the detection of marginal RCSM was 28%. Specificity for RCSM overall was 88%.

The detection of RCSM with a combination of two or three methods was simulated a posteriori (Table 3). The combination of fluoroscopy and X-ray appeared to be the most specific for the detection of RCSM (88%), with increased sensitivity in relation to 3D-fluoroscopy alone (75% vs. 68%). The combination of DVT and 3D-fluoroscopy showed the same sensitivity as DVT alone (88%) with an increase of specificity (73% vs. 53%). Taking X-ray additionally into account to DVT and 3D-fluoroscopy did not appear of additional value for this combination (decreased sensitivity of 60% vs. 73%).

4. Discussion

This study investigates the diagnostic applicability of 3D intraoperative flat panel imaging for the detection of radiocarpal intraarticular screw misplacement (RCSM) in the process of radius plate implantation. With the hypothesis that intraoperative flat panel imaging is as good as HRCT for depicting intraarticular screw misplacement. We compared these methods to the standard postoperative two plain radiographies and the HRCT as the reference method.

However, in regard to the endpoint RCSM, neither the flat panel imaging nor the conventional X-ray were able to allow a reliable diagnosis. The two experienced investigators had a low sensitivity to detect RCSM, especially when using the projectional imaging techniques, X-ray and 3D fluoroscopy. Comparable to the improvement of the sensitivity that has been reported for the X-rays of the wrist when using additional tilted angle projections, the additional tilted angle projections of 3D fluoroscopy improved sensitivity by about 10% [16,17].

The fact that the good image quality of projectional imaging does not assure adequate sensitivity towards main endpoints of the investigation does reflect a problem that the clinicians are facing in the daily routine. Although many radiologists might sign the report of the wrist X-ray after radius plate implantation as normal, there remains a high prevalence of uncertain cases and misjudgements of periarticular screws to be assumed [18]. The investigators were primed that a high incidence of intraarticular screw misplacements was to be detected, so that they did not trivialize their verdict. This study setting revealed the low confidence towards the screw placement which will likely remain subliminal in clinical routine. For fluoroscopy and radiography, only two thirds of the periarticular screws were judged with high confidence in regard to the correct periarticular position, although the image quality was rated to be very good. The lack of confidence was described to be associated with the anatomy of the radiocarpal joint, just as it has been reported in earlier investigations of plain radiographs in comparison to computed tomography of distal radius fractures by Cole et al. [19].

For DVT, the confidence towards screw positioning appeared to be better than for the other two modalities, although the investigators rated the image quality of DVT overall as poor due to artefacts. Artefacts and low resolution of the DVT let to a high rate of false positive reports of intraarticular screw misplacement for this modality. In the majority of these false positive cases, the investigators reported insecurity about their finding due to artefacts. The number of false positive verdicts in the DVT analysis appeared to be higher than it was the case for X-ray and 3D-fluoroscopy. However, the DVT provided acceptable sensitivity, in opposite to X-ray and 3D-fluoroscopy.

This study has several limitations. The fact that the evaluation of all images was performed by two specialists, with long experience does not reflect the reality of intraoperative assessment of joint penetration where the analysis is performed more rapidly. A strength and limitation of this study was that no clinical information could be provided. A major limitation of this study is that the CT as gold standard does yield the possibility of misinterpretation. Given the sensitivity and specificity that we registrated for X-ray, DVT and 3D-fluoroscopy, also post-processed CT could be prone to minor artefacts and therefore could lead to oversensitive performance towards intraarticular or periarticular misplacement. However, the good data quality after post-processing and the high quality standards of the data selection suggest to us, that the CT dataset that we provided is reliable. Further, the CT is the reference in clinical routine. The small size of the study limits the statistical strength of the dataset, especially for the cases of marginal screw misplacement, but appeared to be powerful enough to show the limitations of the methods towards the study endpoint.

It is well possible that further adaption to the manufactures protocols as well as additional post-processing of DVT and 3D-fluoroscopy could lead to further improvements in detection of RCSM. Further, a methodological aspect of the applied DVT imaging should be taken into regard. For DVT data acquisition, only a 90° rotation was used. Therefore, image quality was expected to be worse than that of the CT. As CT uses a minimum rotation angle of 180° (plus fan angle) for proper image acquisition. In return, DVT image quality shall be significantly improved if a 180° scan-angle were applied. This may be subject to future investigations.

5. Conclusion

Although our investigators did show a high motivation, skill and experience, the sensitivity to detect intraarticular screw misplacement was surprisingly very low, especially for the standard method X-ray in two planes (58%). The higher sensitivity of the DVT in comparison to other methods was associated with a decrease of specificity that could be improved to certain extents, when combining the two intraoperative methods, DVT and 3D-fluoroscopy (sensitivity: 88%, specificity: 75%). We therefore conclude that in order to compete with CT, improvements in data acquisition and post-processing techniques for 3D-fluroscopy and DVT images are needed. Still, under ideal diagnostic conditions, the intraoperative imaging with DVT and 3D-fluoroscopy appear to be at least as sensitive and specific to detect RCSM as the regular postoperative radiography in two planes. However, especially discrete screw misplacements can be missed with either method. Thus, neither the flat panel imaging nor conventional X-rays, nor their combination allow a reliable diagnosis. In cases of a negative X-ray report and clinical complaints after radius plate implantation, additional tilted angle projections or a CT should be performed. However, even the use of CT did not allow a reliable diagnosis in all cases.

Disclosure of interest

The authors declare that they have no competing interest.

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HB and JB contributed equally to this work.

References

[1] Cooney 3rd WP, Linscheid RL, Dobyns JH. External pin fixation for unstable Colles' fractures. J Bone Joint Surg Am 1979;61:840–5.
[2] Leung KS, Shen WY, Tsang HK, Chiu KH, Leung PC, Hung LK. An effective treatment of comminuted fractures of the distal radius. J Hand Surg Am 1990;15:11–7.
[3] Ono H, Furuta K, Fujitani R, Katayama T, Akahane M. Distal radius fracture arthroscopic intraarticular displacement measurement after open reduction and internal fixation from a volar approach. J Orthop Sci 2010;15:502–8.
[4] Knirk JL, Jupiter JB. Intra-articular fractures of the distal end of the radius in young adults. J Bone Joint Surg Am 1986;68:647–59.
[5] Benson LS, Minihane KP, Stern LD, Eller E, Seshadri R. The outcome of intra-articular distal radius fractures treated with fragment-specific fixation. J Hand Surg Am 2006;31:1333–9.
[6] Drobetz H, Bryant AL, Pokorny T, Spitaler R, Leixnering M, Jupiter JB. Volar fixed-angle plating of distal radius extension fractures: influence of plate position on secondary loss of reduction – a biomechanic study in a cadaveric model. J Hand Surg Am 2006;31:615–22.
[7] Mehling I, Muller LP, Delinsky K, Mehler D, Burkhart KJ, Rommens PM. Number and locations of screw fixation for volar fixed-angle plating of distal radius fractures: biomechanical study. J Hand Surg Am 2010;35:885–91.
[8] Pace A, Cresswell T. Use of articular wrist views to assess intra-articular screw penetration in surgical fixation of distal radius fractures. J Hand Surg Am 2010;35:1015–8.
[9] Thomas AD, Greenberg JA. Use of fluoroscopy in determining screw overshoot in the dorsal distal radius: a cadaveric study. J Hand Surg Am 2009;34:258–61.
[10] Tweet ML, Calfee RP, Stern PJ. Rotational fluoroscopy assists in detection of intra-articular screw penetration during volar plating of the distal radius. J Hand Surg Am 2010;35:619–27.
[11] Bradway JK, Amadio PC, Cooney WP. Open reduction and internal fixation of displaced, comminuted intra-articular fractures of the distal end of the radius. J Bone Joint Surg Am 1989;71:839–47.
[12] Arora R, Lutz M, Hennerbichler A, Krappinger D, Espen D, Gabl M. Complications following internal fixation of unstable distal radius fracture with a palmar locking-plate. J Orthop Trauma 2007;21:316–22.
[13] Grewal R, Perey B, Wilmink M, Stothers K. A randomized prospective study on the treatment of intra-articular distal radius fractures: open reduction and internal fixation with dorsal plating versus mini open reduction, percutaneous fixation, and external fixation. J Hand Surg 2005;30:764–72.
[14] Meier R, Geerling J, Hufner T, Kfuri M, Krettek C. The isocentric C-arm. Visualization of fracture reduction and screw position in the radius. Der Unfallchirurg 2011;114:587–90.
[15] Meier R, Geerling J, Hufner T, Kfuri M, Krettek C. The isocentric C-arm. Visualization of fracture reduction and screw position in the radius. Unfallchirurg 2011;114:587–90.
[16] Smith DW, Henry MH. The 45° pronated oblique view for volar fixed-angle plating of distal radius fractures. J Hand Surg 2004;29:703–6.
[17] Takemoto RC, Gage M, Rybak L, Zimmerman I, Egol KA. Accuracy of detecting screw penetration of the radiocarpal joint following volar plating using plain radiographs versus computed tomography. Am J Orthop 2012;41:358–61.
[18] Gasse N, Lepage D, Pem R, Bernard C, Lerais JM, Garbuio P, et al. Anatomical and radiological study applied to distal radius surgery. Surg Radiol Anat 2011;33:485–90.
[19] Cole RJ, Bindra RR, Evanoff BA, Gilula LA, Yamaguchi K, Gelberman RH. Radiographic evaluation of osseous displacement following intra-articular fractures of the distal radius: reliability of plain radiography versus computed tomography. J Hand Surg Am 1997;22:792–800.