Florian Streitparth[a], Christian Althoff[a], Martin Jonczyk, Felix Guettler, Martin Maurer, Hendrik Rathke, Keno Moritz Sponheuer, Bernd Hamm, Ulf K. Teichgräber and Maximilian de Bucourt*

Tailored interactive sequences for continuous MR-image-guided freehand biopsies of different organs in an open system at 1.0 tesla (T) – Initial experience

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Abstract

Objectives: To assess the feasibility, image quality, and accuracy of freehand biopsies of liver, bone, muscle, vertebral disc, soft tissue, and other lesions using balanced steady-state free precession (SSFP, balanced fast field echo: bFFE), spoiled and nonspoiled gradient echo (FFE), and turbo spin echo (TSE) sequences for interactive continuous navigation in an open magnetic resonance imaging (MRI) system at 1.0 tesla (T).

Methods: Twenty-six MR-guided biopsies (five liver, five bone, four muscle, four vertebral disc, one lung, one kidney, one suprarenal gland, and five soft or other tissue) were performed in 23 patients in a 1.0-T open magnetic resonance (MR) scanner (Panorama HFO, Philips Healthcare, Best, the Netherlands). A total of 42 samples were obtained. Depending on lesion size and location, 14–18-gauge MR-compatible biopsy sets with a length of 100 or 200 mm (Somatex Medical, Teltow, Germany), 14–18-gauge MR-compatible semiautomatic biopsy guns with a length of 100 or 150 mm (Invivo, Schwerin, Germany), or 11-gauge MR-compatible bone marrow biopsy needles with a length of 100 mm (Somatex Medical, Teltow, Germany) were employed.

Results: All lesions were visible with continuous interactive imaging. Our initial results indicate that bFFE is particularly suitable for fast-moving organs (pulmonary, paracardial); moving organs are targeted better with T1-weighted (T1W) TSE, T1W FFE (liver) or T2-weighted (T2W) TSE (complicated cysts, adrenal glands), and static organs are successfully approached with proton density (PD) (spine) or T1W TSE (peripheral bones, musculoskeletal system). No adverse events related to the use of MRI were obtained. No complications occurred according to the Society of Interventional Radiology (SIR) clinical practice guidelines.

Conclusion: Applying tailored interactive dynamic imaging sequences for continuous navigation to liver, bone, muscle, vertebral disc, soft tissue, and other lesions can improve the feasibility, image quality, and interventional accuracy of freehand MR-guided biopsies and may hence reduce the risk of complications.

Keywords: biopsies; MRI; real-time image guidance.

[a]Florian Streitparth and Christian Althoff contributed equally to this work.

***Corresponding author: PD Dr. med. Maximilian de Bucourt,** Dipl. Vw., Head Angiography Campus Benjamin Franklin (CBF), Department of Radiology, Charité CBF, Charité – University Medicine Berlin, Hindenburgdamm 30, 12203 Berlin, Germany, Pieper 4780, Phone: +49 30 450 527 085, Fax: +49 30 450 7 627 085, E-mail: mdb@charite.de

Florian Streitparth, Christian Althoff, Martin Jonczyk, Keno Moritz Sponheuer and Bernd Hamm: Department of Radiology, Charité – University Medicine Berlin, Berlin, Germany

Felix Guettler and Ulf K. Teichgräber: Department of Radiology, Friedrich-Schiller-University, Jena, Germany

Martin Maurer: Department of Radiology, Inselspital, Bern University, Switzerland

Hendrik Rathke: Department of Radiology and Nuclear Medicine, University of Heidelberg, Germany

Introduction

Biopsy remains the gold standard for identifying and evaluating many benign and malignant pathologies. This medical test is commonly performed by surgeons or interventional radiologists, and the tissue is generally microscopically examined by pathologists [1, 2, 16]. Interventional radiologists can use any imaging modality [ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI)] to perform biopsies [6, 11, 15], each having a specific set of disadvantages and advantages. The key aspects for deciding which imaging modality to choose include radiation dose, accessibility, and

visualization (especially soft tissue contrast) of the lesion. Possible disadvantages often attributed to ultrasound include user dependence of image acquisition and poor visualization of targets located deeper in the body. For CT, possible disadvantages include radiation exposure for patients (and possibly also for the interventionalist) as well as possible idle times or delays of the often highly frequented, utilized, and occupied imaging modality. Advantages of ultrasound include the straightforward and comparably quick approach without large-scale machine setup or the need for technicians. For CT, short procedure times and accurate planning as well as image validation may be regarded as advantages.

Several recent developments in the field of MRI have made this modality an appealing option for interventions, including biopsies as well. These developments include new MR system designs (from narrow tunnel to larger bore and open systems), the advent of suitable MR-compatible needles [23], the provision of useful accessories (e.g. the MR-compatible mouse for in-room navigation [18]), the increase in magnetic field strength, and the establishment of a variety of fast imaging sequences (which enable near-real-time imaging). Other features that make MRI appealing for interventions are its excellent soft tissue contrast, the absence of radiation exposure, and the possibility of arbitrary slice selection in any desired angle. The multiplanar capability can be used to continuously visualize a needle while maneuvering it to even delicate target locations with near-real-time imaging.

Our group has been performing and investigating MR interventions for many years (including, for example, pain treatments: MR-guided periradicular, epidural, facet joint, and iliosacral joint infiltrations). Therefore, the question arose as to whether we may make better use of the specific features of the various MR sequences that allow near-real-time imaging. With our experience gained with different interventional pulse sequences and their features in terms of image acquisition rates, needle artifact size and visibility, and tissue contrast, one may specify which sequence may be best used in which circumstance. As biopsies are performed in almost all organs and tissues in the human body (including superficial and deep locations, as well as static and moving organs including organs affected by breathing movement), it seemed reasonable to systematically review the experience gained with different pulse sequences in obtaining biopsies.

Based on a thorough literature review, this manuscript is, to our knowledge, the first report presenting an approach for further refining and tailoring interactive sequences for continuous MR-guided freehand biopsies of different organs in an open system at 1.0 tesla (T).

The purpose of this study was to assess the feasibility, image quality, and accuracy of freehand biopsies using balanced steady-state free precession [SSFP, balanced fast field echo (bFFE)], spoiled and nonspoiled gradient echo (FFE), and turbo spin echo (TSE) sequences for continuous near-real-time needle guidance in an open MRI system at 1.0 T.

Materials and methods

Institutional Ethics Committee approval and written informed consent were obtained. This study was supported by the Technologiestiftung Berlin (TSB) – Zukunftsfonds Berlin, Berlin, Germany, and the European Union – European Fund for Regional Development, Berlin, Germany. The authors declare that there is no actual or potential conflict of interest in relation to this article.

Study design

Twenty-six MR-guided biopsies (five liver, five bone, four muscle, four vertebral disc, one lung, one kidney, one suprarenal gland, and five soft and other tissue) were performed in 23 patients in a 1.0-T open magnetic resonance (MR) scanner (Panorama HFO, Philips Healthcare, Best, the Netherlands). A total of 42 samples were obtained. The MR system has a light-weight, vertical-field, superconducting magnet, and a built-in solenoid technology transmit/receive quadrature body coil. Surface body coils were used according to the anatomic region whenever the interventional access route permitted it. A gap of 45 cm between the tabletop and the upper cover of the MR system allows access to the patient from the sides. The patient aperture (width) is 160 cm, and the maximum field of view (FOV) is 45 cm.

Complications were recorded according to the Society of Interventional Radiology (SIR) clinical practice guidelines [20]. Average patient age was 55 ± 21 years (min. 10, max. 80). There were eight female and 15 male patients. For interactive continuous navigation, different interventional sequences [T1-weighted (T1W), proton density (PD), and T2-weighted (T2W)] with different echo time (TE), repetition time (TR), and flip angle parameters were applied: balanced SSFP (balanced fast field echo: bFFE; gradient + spin echo), gradient echo (FFE; spoiled T1W FFE and nonspoiled), and TSE sequences (see Table 1).

As interventions were performed in different organs and tissues, the subjective peri-interventional appearance of needle artifact sensitivity (in terms of brightness, contrast, and delineation from the surrounding tissue) and the signal-to-noise ratio (SNR) were assessed and related to the image acquisition rate for each of the interventional sequences used.

Interactive continuous navigation procedure

All MR-guided biopsies were performed using an MR-compatible in-room monitor and an MR-compatible wireless universal serial bus (USB) personal computer (PC) mouse, aseptically hand-operated by

Table 1: Interactive sequences used for image-guided biopsies.

Sequence	Image acquisition rate	Signal-to-noise ratio (SNR)	Needle artifact sensitivity
Balanced SSFP (bFFE) Parameters: – TE 2.2 – TR 4.4 – Flip angle 40–45	Very high ▲▲▲ (1.3 s per image)	Very low ▼▼▼	Very high ▲▲▲
Gradient echo (FFE) Parameters: Spoiled (T1W): – TE 6 – TR 12 – Flip angle 35 Nonspoiled (T2*): – TE 15 – TR 24 – Flip angle 15	High ▲▲ (2.0 s per image)	Low ▼▼	High ▲▲
Turbo spin echo (TSE) Parameters (T1W; PDW; T2W): – TE 5.7; 10; 90 – TR 200; 600; 1000 – Flip angle 90; 90; 90	Low ▼ (3–4.4 s per image)	High ▲	Low ▼

the interventional radiologist performing the intervention. The in-room monitor is synchronized with the MR system's console in the technician's operating room outside the scanner room. The interactive sequences were embedded in the scanner software (MR Systems Panorama HFO Release 2.6.5.0 2009-09-30, Philips Healthcare, Best, the Netherlands). In interactive mode, a 2×2 image matrix is displayed and can be manually filled with single-shot images in different, interactively selected planes: (para-)transverse, (para-) sagittal, and (para-)coronal. As usual for multiplanar reconstruction (MPR), intersections of the images are visualized by a line on the respective other imaging planes. One of the four quadrants can be activated by a mouse click, and thereafter starts repetitive image acquisition of the very slice in the given (possible) short repetition rate. During intervention, the interventionalist can effortlessly choose to activate another plane angulation for image reiteration by clicking on one of the other quadrants, or by modifying the angulation/intersection lines displayed in the respective other images with the PC mouse.

Biopsy

Depending on lesion size and location, 14–18-gauge MR-compatible biopsy sets with a length of 100 or 200 mm (Somatex Medical, Teltow, Germany), 14–18-gauge MR-compatible semiautomatic biopsy guns with a length of 100 or 150 mm (Invivo, Schwerin, Germany), or 11-gauge MR-compatible bone marrow biopsy needles with a length of 100 mm (Somatex Medical, Teltow, Germany) were employed. All MR interventions were performed by three physicians with respective 10, 5, and 4 years of experience, including profound experience in CT biopsy interventions. If possible, present, and necessary, fluid was aspirated for microbiological analysis as well (e.g. fluid in disc sign as a possible indicator of spondylodiscitis).

Results

All lesions were visible with continuous interactive imaging. Depending on the organ harboring, the lesion to be approached and on the surrounding tissue, continuous image acquisition for biopsy was performed with bFFE, FFE, or TSE sequences. Figures 1–3 illustrate MR-image-guided freehand tissue sampling from different organs with the use of different sequences.

Our initial results indicate that bFFE is particularly suitable for fast-moving organs (pulmonary, paracardial); moving organs are targeted better with T1W TSE, T1W FFE (liver), or T2W TSE (complicated cysts, adrenal glands), and static organs are successfully approached with PD (spine) or T1W TSE (peripheral bones, musculoskeletal system). The TE, TR, and flip angle parameters are provided in Table 1. Qualitative estimates of SNR and artifact sensitivity are also reported as they may affect the choice of the adequate sequence for a given MR-guided intervention.

We saw no adverse events related to the use of MRI. No complications occurred according to the SIR clinical practice guidelines [20]. The average lesion size was 35 mm (range 15–65). Out of the 26 MR-guided biopsies with 42 samples obtained in 23 patients, histopathology results were malignant in five patients (hepatocellular carcinoma, cholangiocellular carcinoma, metastasis of colorectal carcinoma, atypical lipoma/liposarcoma,

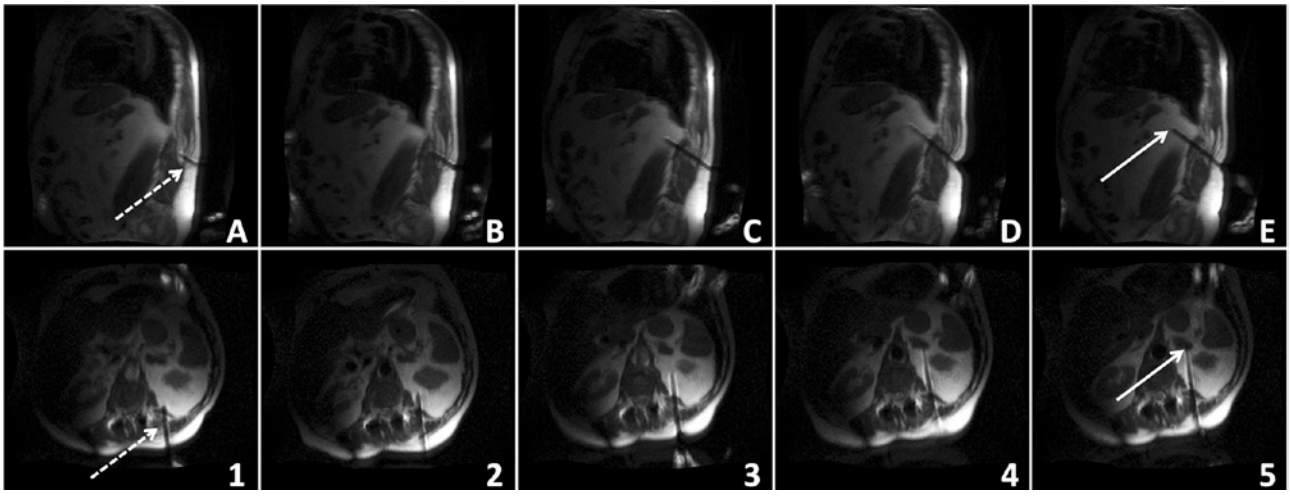

Figure 1: Progress of an adrenal gland biopsy in para-sagittal (A–E) and para-transversal (1–5) image acquisitions, applying a T2W TSE sequence.
Note that the needle artifact can be displayed in its entirety in both imaging planes because the angulation of the plane to be acquired can be chosen freely and easily. Hence, 178 other degrees could also be chosen to display the needle's artifact in the tissue completely (unless, of course, the needle is bent, compare discussion). The dashed arrows in A and 1 depict an initial needle position, before the needle is further advanced to finally reach the adrenal gland (continuous arrows in E and 5).

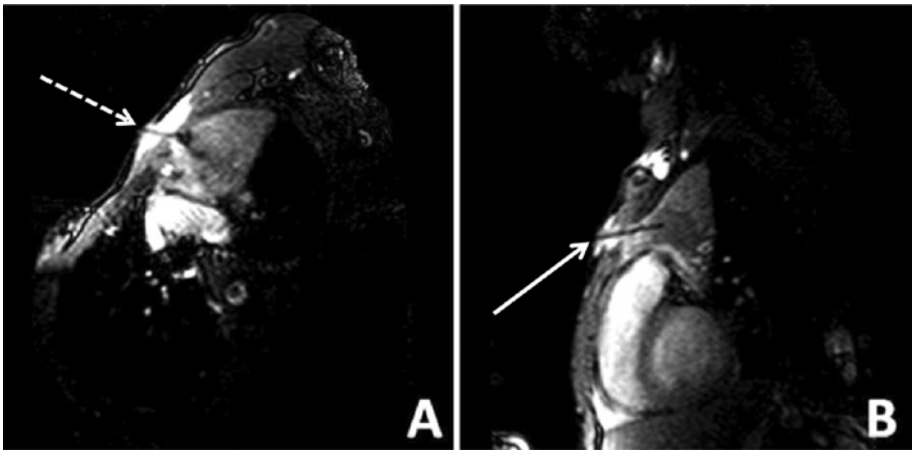

Figure 2: Para-transversal (A) and para-sagittal (B) image acquisitions during a lung biopsy, applying a bFFE sequence (dashed arrow in A pointing to the needle artifact in the para-transversal and continuous arrow in B pointing to the needle artifact in the para-sagittal planes).

lymphomatoid granulomatosis), benign (including possibly false negative) in eight (cavernous hemangioma, cystic formations, inconspicuous skeletal muscle, tight connective tissue, regular target parenchyma), inflammatory in five (spondylodiscitis, spondylitis, abscess), and of other qualities in five patients (sarcoidosis, tumor-like calcinosis in hyperparathyroidism, scarred fibrotic lung parenchyma with mild chronic inflammation, inconclusive tissue). According to our preliminary results, MR-guided biopsies were performed with a high technical success rate.

Discussion

To perform interventions, imaging modalities like ultrasound, CT, and MRI are all used, which have their own pros and cons [6, 7, 13, 14]. Many technical advances have improved the use of MRI for guiding interventions, and there are ongoing efforts to make MRI even more appealing for this purpose: an open MRI system not only allows imaging of excessively obese patients [8] but can also be used to perform interventions such as spinal injection procedures [22], lumbosacral periradicular injection therapy [21],

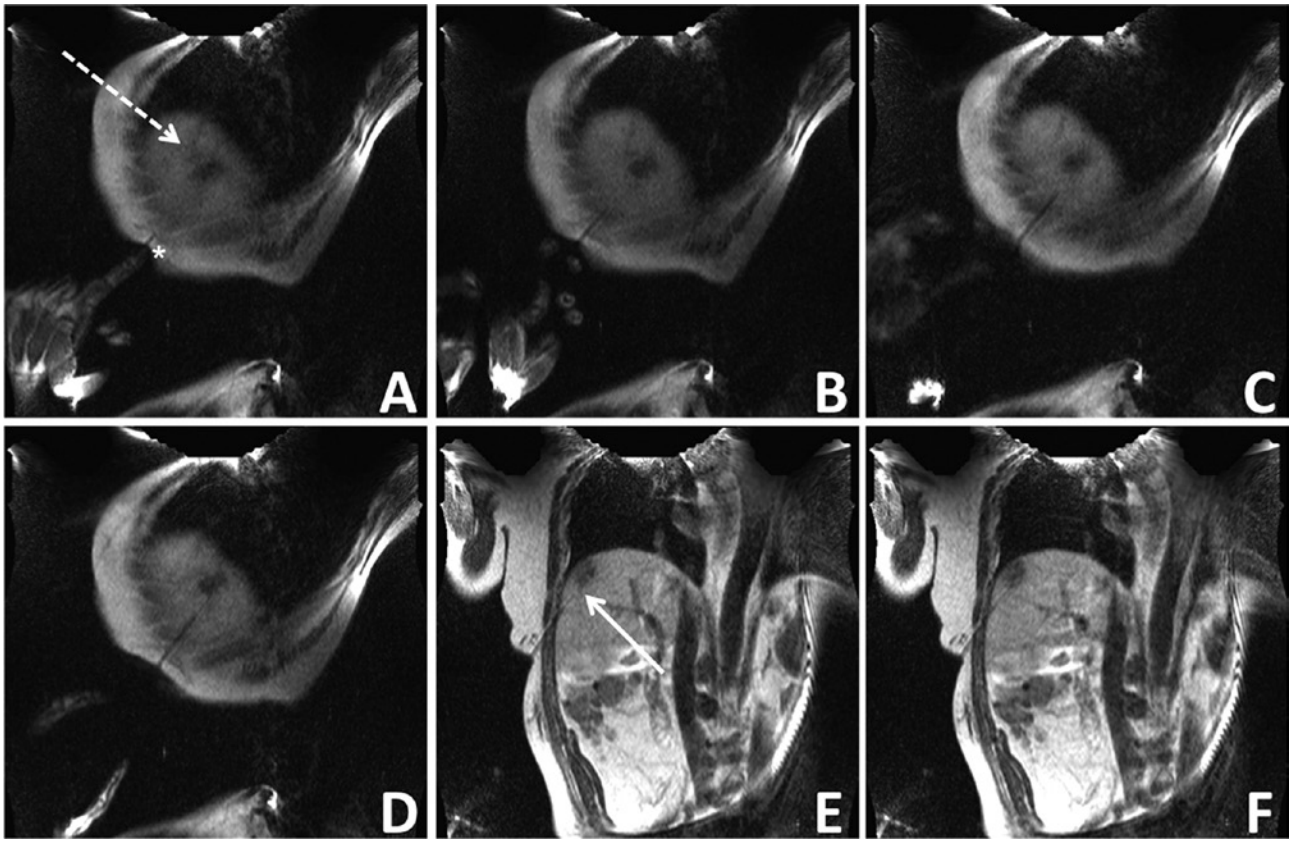

Figure 3: Para-transversal (A–D) and para-sagittal (E, F) images acquired during a liver biopsy applying a T1W TSE sequence.
Note the visualization of the interventionalist's finger (finger-pointing technique; asterisk) in A to orientate to needle. Dashed arrow in A: hepatic lesion/biopsy target. Continuous arrow in E: advanced needle as visualized by the needle artifact with the lesion in front of the needle tip. Note the difficulty of reaching the hepatic lesion due to its challenging subphrenic location and structures in the immediate vicinity: with the ability of arbitrary near-real-time image angulation in MR, it is possible to spare the costodiaphragmatic recess.

and facet joint injection therapy [12]. Useful accessories for interventions have been developed, including the MR-compatible PC mouse for in-room use by the interventionalist [18]. MRI enables retrieval of additional physical information during interventions such as MR thermometry [24], e.g. for intradiscal temperature monitoring [25]. MR volumetry can be used to assess volumes and possible effects of fluid preinjection in ablation procedures such as radiofrequency ablation (RFA) or microwave ablation (MWA) [5]. Even experimental laparoscopic liver resection under MR guidance has been performed in animals [3, 4].

Most departments, however, continue to perform many or most interventions using CT guidance, as it is convenient, quick, successful, and readily available. Rimondi et al. recently published a study of CT-guided biopsies of the musculosceletal system performed in their institution over an 18-year period. Based on this analysis, which comprised no less than 2027 cases [19], they concluded that CT guidance should be considered the gold standard. However, MRI undoubtedly offers benefits, especially a sound soft tissue contrast as well as no radiation exposure (neither for the patient nor possible scattered radiation exposure for the interventionalist).

Compared to CT-guided biopsies, the excellent soft tissue contrast of the MRI approach without radiation as well as the option of arbitrary slice selection with multiplanar near-real-time visualization for maneuvering even to delicate locations may increase future demand and use of MR-guided biopsies for some organs and regions. Also, MRI can detect lesions that are not (yet) visible with other imaging modalities such as CT or ultrasound. The possibility to perform steeply angulated needle maneuvers as illustrated in Figure 3 (E and F) may furthermore be regarded as an advantage of MR-guided interventions. In the case depicted, it was possible to safely access an extremely cranial subphrenic hepatic lesion in segment 7/8 without having to pass the costodiaphragmatic recess and, hence, to access the pleural cavity. Due to technical restrictions in CT, arbitrary near-real-time slice selection is not possible, and only experienced interventional

radiologists may accomplish similar results by maneuvering the needle in an out-of-plane fashion through the body. Another appealing alternative for such cases may be to use fusion imaging [9, 10, 17].

In MR-guided interventions, one may also take advantage of maneuvering arcuated needles through tissue while still having complete near-real-time visualization of the needle artifact in a freely selectable imaging plane as demonstrated in Figure 4: in this case, the L5/S1 intervertebral disc was targeted. In order to keep the distance to the nerve root as long as possible, the needle was bent and maneuvered into the disc from as far caudally as possible.

Applying tailored interactive dynamic imaging sequences for continuous navigation to liver, bone, muscle, vertebral disc, soft tissue, and other lesions can improve the feasibility, image quality, and interventional accuracy of freehand MR-guided biopsies and may, hence, reduce the risk of complications. Even though there may still be a long way to go on the way to tailoring interactive sequences to the specific needs for targeting different lesions and locations, it will ultimately contribute to a wider acceptance of MR-guided interventions. The technique of continuous MR-guided freehand biopsies may be especially useful when devices have to be maneuvered to delicate target locations.

Limitations

Our study has several limitations. We report our initial, single-centre experience in a small number of patients. Also, we used the interventional near-real-time MR sequences available to us, which are by no means claimed to be concluding, especially as the number of sequences is continuously increasing. Generalizations or simply transferring our results to other MR systems may not be adequate, as sequences may perform differently and needle artifacts may be visualized differently in different scanners (e.g. open vs. tunnel systems) and field strengths.

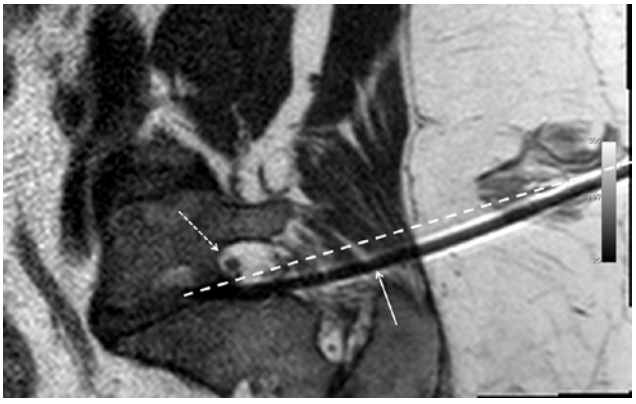

Figure 4: Example of a bent needle maneuvered into the L5/S1 intervertebral disc while still having complete near-real-time visualization of the artifact along the access route.
In order to keep the distance to the nerve root (dashed arrow) as long as possible, the needle was arcuated and maneuvered into the disc from as far caudally as possible. The white dashed line indicates the usual straight course of a needle artifact (continuous arrow).

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