Original Research

MR-Guided Bone Biopsy: Preliminary Report of a New Guiding Method

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Purpose: To evaluate the feasibility of a new MR compatible optical tracking guided bone biopsy system.

Materials and Methods: Wireless optical tracker elements were connected to a bone biopsy set. Biopsies of five different anatomic areas and lesions varying from 9 mm to 40 mm (mean 25 mm) in size, were performed.

Results: We were able to perform the biopsies in all cases, and the samples allowed for a pathologic diagnosis. The procedure time was limited to less than 40 minutes, and no complications occurred.

Conclusion: MR-guided bone biopsy with this new guiding system was a feasible and fast procedure that did not compromise the usability of the bone biopsy set.

Key Words: magnetic resonance imaging; interventional MRI; bone biopsy; bone neoplasms; bone diseases
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PERCUTANEOUS (FLUOROSCOPIC OR COMPUTED TOMOGRAPHY [CT]-GUIDED) bone biopsy is a feasible alternative to open biopsy (1–4). The initial results of magnetic resonance (MR)-guided bone biopsies are encouraging (5). MRI's high sensitivity in detecting bone and bone marrow lesions and its superior soft tissue contrast allow good visualization of the pathology and puncture route without ionizing radiation. Optical tracking can be used to guide pre-operative planning and intra-operative scanning of the procedure (6). This is, to our knowledge, the first study to test a system where optical tracker elements are connected to a bone biopsy set, allowing scanning in the plane of the instrument throughout the procedure. The purpose of this study was to evaluate the feasibility of this new MR-compatible optical tracking guided bone biopsy set.

MATERIALS AND METHODS

The biopsies were performed using a bone biopsy set, which was connected to an optical tracking system. An MR-compatible bone biopsy set (BoneBiopsy™, Daum GmbH, Germany) with two different drill bits (∅ 3 and 6 mm) was designed in our institution to be connected with an optical tracking system (Fig. 1). All parts of the set were made of a special titanium alloy that permits usage in MR imagers up to 1.5-T. Because the titanium alloy is softer than stainless steel, special teeth that allow rotational drilling without axial pressure were created. The patented surface treatment of the cannulas provided safe clinical use. The biopsy set was connected to the optical tracking system with a wireless instrument holder (Fig. 2). It is a sterilizable tool made of biocompatible plastic and equipped with infrared (IR)-reflecting spheres suited for optical tracking. The holder is part of the interventional MRI package (*i*Path 200) provided by the magnet (Proview) manufacturer (Marconi Medical Systems, Cleveland, OH). The magnet was an open configuration C arm 0.23-T magnet (Fig. 3), which was installed in the operating room. The interventional MR imaging (IMRI) package consisted of an MR-compatible in-room console, a large-screen (36") display, optical navigator hardware, and IMRI software. The display uses a projector integrated with a backlit screen. It is capable of showing four to six images with XVGA resolution at a viewing distance of 2–4 m. The navigator camera is placed on an adjustable and movable stand. The camera utilizes IR passive tracking, whereby the position of the instrument being observed is calculated from the IR pulses reflected from the spheres attached rigidly to the bone biopsy set. The camera is capable of differentiating between instrument types based on the geometrically unique configurations of the spheres on the instruments. The fixed reference frame attached to the upper polepiece of the magnet allows repositioning of the camera during the operation, in case the line-of-sight to the needle holder becomes blocked. Optical tracking allows imaging in the plane of the needle both before needle insertion and during the whole procedure. With optical tracking, the needle and its estimated path can be seen real-time as graphical overlays on all images taken previously.

The feasibility of this new guiding system was evaluated with biopsies of five different anatomic areas (Table

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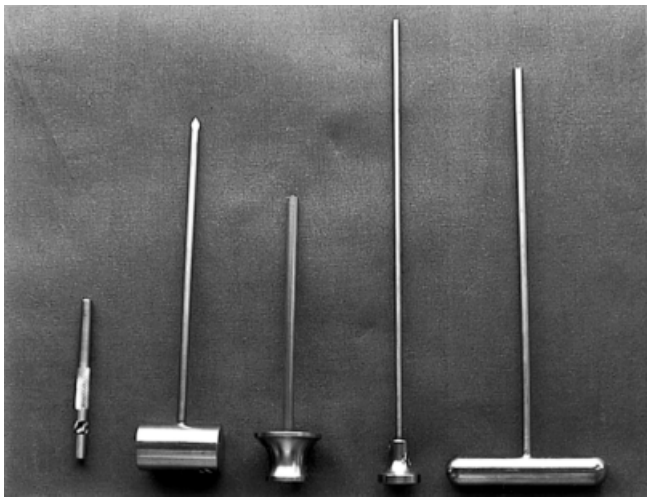


Figure 1. Components of the bone biopsy set (from left): 1) connector to instrument holder, 2) stylet, 3) working tube, 4) ejector drift and 5) drill.

1). Informed consent was obtained from all patients in advance of the procedure. All the patients had had a bone lesion detected in previous plain film radiography (one patient), CT (three patients) or MR imaging (one patient). Only one of the lesions (patient 1, Table 1) was clearly seen in plain film radiography, while CT showed three out of four lesions imaged with CT. The sizes of the lesions varied from 9 to 50 mm (mean 25 mm). Two of the lesions were in the spine, one in the sacral bone, one in the femoral head, and one in the femoral diaphysis. The highest demands for needle placement were presented by one of the spinal lesions (Th 7), which was punctured via the transpedicular route, and the smallest lesion (0.9 cm) in our series was located in subchondral bone in the femoral head. A previous malignancy was known in one patient. Two biopsies were performed under general anesthesia and three under spinal anesthesia.

Pre-operatively, the lesion and the puncture route were visualized with T1-weighted fast spin-echo (FSE; TR/TE 400/16 msec, echo train length (ETL) 4, flip angle (FA) 90°, field of view (FOV) 380 mm × 380 mm, acquisition matrix 324 × 324, 7-mm slices, time of acquisition (TA) 22 seconds, five slices) in a longitudinal, either sagittal or coronal, plane, depending on the anatomical area. The site of skin puncture was determined with optical tracking. The following needle guidance sequences were used: 1) T1-weighted gradient-echo (TR/TE 95/7, ETL 1, FA 60, FOV 380 × 380, matrix 300 × 300, 7-mm slices, TA 18 seconds, five slices), 2) C-BASS two-dimensional (completely balanced steady state sequence) (TR/TE 9.1/4.5, ETL 1, FA 60, FOV 380 × 380, matrix 216 × 216, 10-mm slice, TA 2 seconds, one slice), and 3) C-BASS three-dimensional (TR/TE 8.4/4.2, ETL 1, FA 45, FOV 380 × 380, matrix 256 × 256, 5-mm slices, TA 24 seconds, eight slices). The biopsies were targeted to the enhancing part of the tumor, if one had been present in the previous MR images. When the lesion's border was reached, the stylet was removed and the drill in Figure 1 was introduced through the working tube. The bore was then drilled into the lesion, and a sample was removed and fixed in 10% formalin. The patients remained in the hospital for 24 hours for routine follow-up.

RESULTS

The bone biopsy system was successfully applied to all patients, and it provided a safe and accurate guidance method for all phases of the procedure. Optical tracking implemented as part of the biopsy set allowed the puncture route to be chosen fast and reliably before needle insertion, and it was also useful during the biopsy procedure whenever the angle of approach had to be changed. Optical tracking also allowed almost real-time imaging in the plane of the instrument, which made the procedure easy to accomplish in different anatomical areas and at different angles of approach, allowing the procedural time from the insertion of the needle

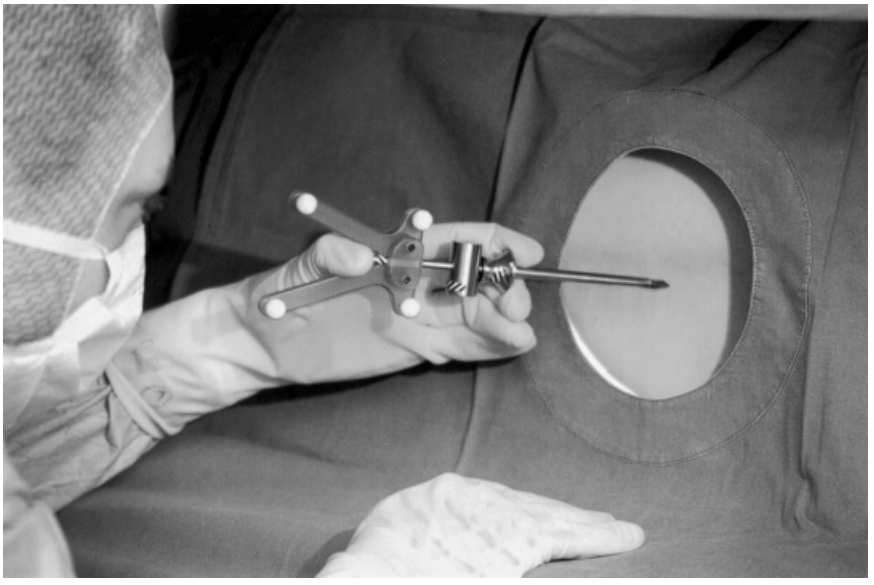


Figure 2. Working tube and stylet with a connector to the wireless instrument holder for optical tracking.

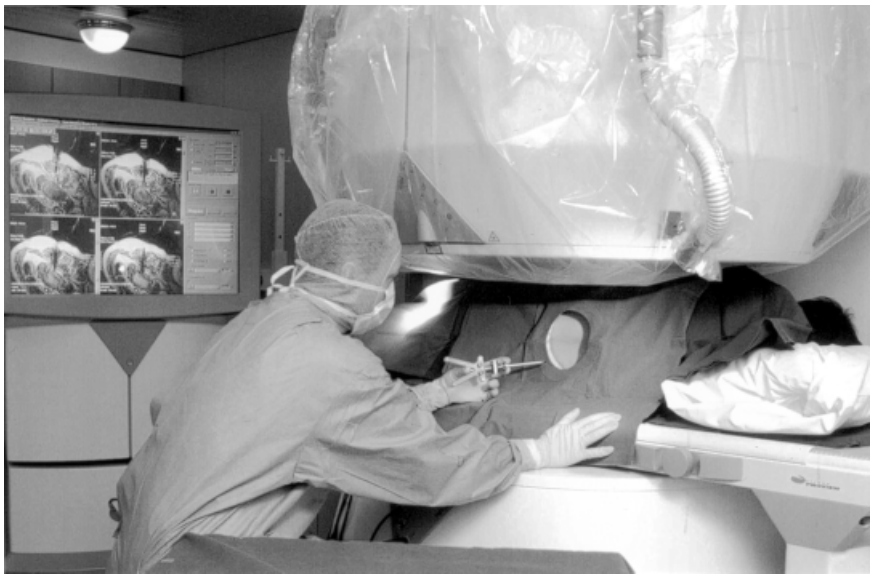


Figure 3. Performing the bone biopsy: wide access to the patient, 36″ display of the IMRI package on the left.

through skin to needle retraction to be less than 40 minutes.

The biopsies performed using this system yielded sufficient samples in all cases (Table 1). The smallest lesion in our series (9 mm), which was located in subchondral bone in the femoral head, was successfully biopsied via the femoral neck without puncturing the cartilage (Fig. 4). One of the vertebral body biopsies (Th 7) was performed via the transpedicular route without difficulties (Fig. 5). The image quality of the 0.23-T scanner was sufficient in all cases, including lesions diagnosed with high-field MR imaging prior to the intervention. No complications occurred.

DISCUSSION

Percutaneous or surgical biopsy is often required to confirm the diagnosis of a bone lesion. Cross-sectional imaging modalities, such as CT or MR imaging, although more time-consuming, allow better visualization of the lesion and the surrounding soft tissues than real-time fluoroscopy. CT has been established as a reliable guidance method in bone biopsies (1–4). Since the mid-1990s, CT fluoroscopy has been used increasingly to guide biopsies, and it offers the localization advantages of CT with improved procedure times (7). Compared to CT and CT fluoroscopy, MR imaging has several advantages, including superior soft tissue contrast, unique three-dimensional imaging capabilities, and a lack of ionizing radiation. Open-configuration C arm magnets allow wide access to the patient (Fig. 3), and the puncture route can be chosen in any plane, as opposed to CT, where the gantry only allows procedures in the axial or near axial planes and limits the usage of long instruments. MR imaging is superior to the other imaging modalities in detecting bone and bone marrow lesions. Contrast-enhanced MR imaging reveals the vascularized and vital parts of a tumor, and MR guidance makes it possible to avoid biopsies of necrotic areas of a tumor.

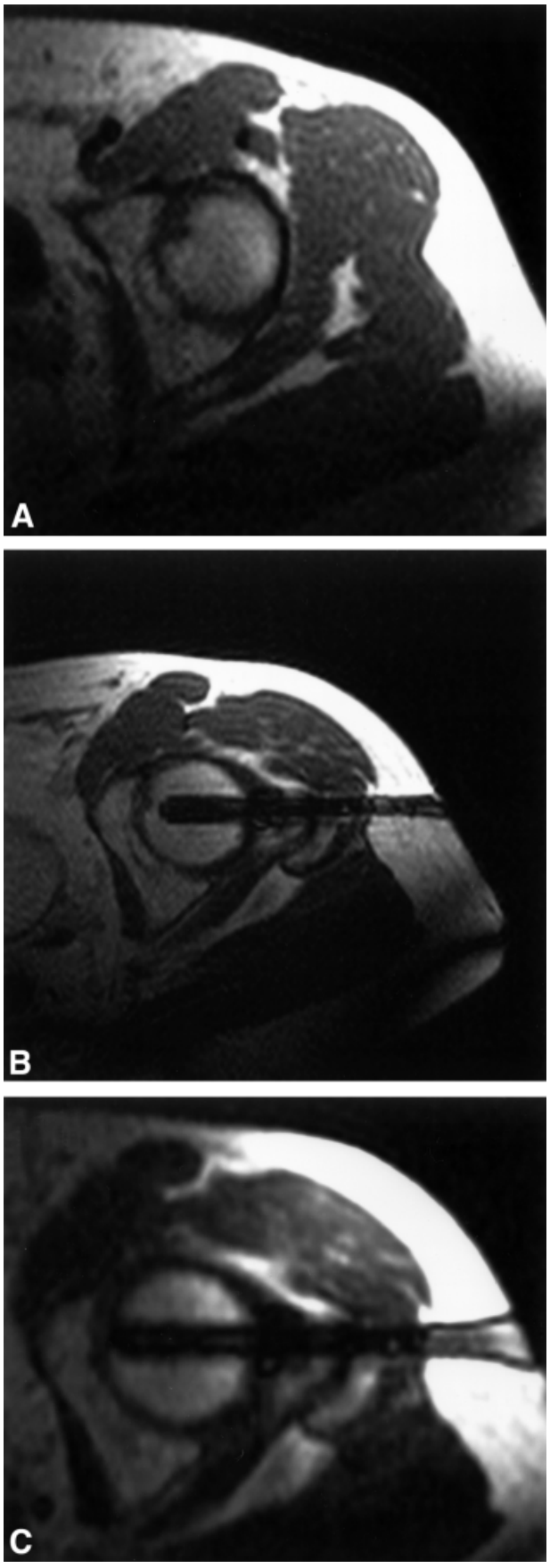
Table 1
Site, Size and Final Diagnosis of Bone Lesions

Patient	Site	Size (mm)	Diagnosis
21 y Female	Th 7[a]	25	Infection
35 y Male	Femoral head	9	Fibrosis
73 y Female	Sacrum	50	Plasmocytoma
31 y Male	L 5[b]	31	Lymphoma
70 y Female	Femur	15	Metastasis

[a]Seventh thoracic vertebra.
[b]Fifth lumbar vertebra.

Real-time imaging with MR imaging is often limited by the achievable signal-to-noise ratio and tissue contrast. Therefore, a modality-independent method for localizing the instrument in real time is beneficial on less frequently updated images. An optical tracking system augments this localization by providing instantaneous feedback (8), while intra-operative MR imaging is used for generating updated roadmaps along the needle path. Compared with passive tracking, where the needle artifact alone is used for deducing the instrument's position and orientation (9), optical tracking offers distinct advantages. The initial needle orientation at the puncture site can be determined with the aid of graphic tools and/or needle-guided scout images, whereas passive tracking requires more elaborate slice positioning and MR-visible markers. In our series, determination of the puncture site was possible with optical tracking overlays in one or two MR imaging sets, and no skin markers were needed. Difficulties in deducing the exact orientation of the needle from its artifact have adverse effects on the overall accuracy of needle alignment, and the acquisition of affirmative images accrues a time penalty. Other active guidance systems, such as ultrasound probes and mechanical arms (10,11) could also be used instead of optical systems, but they lack the flexibility of wireless instrument tracking.

Optical tracking has been successfully used in CT-guided (7) and MR-guided (8) needle biopsies and injec-



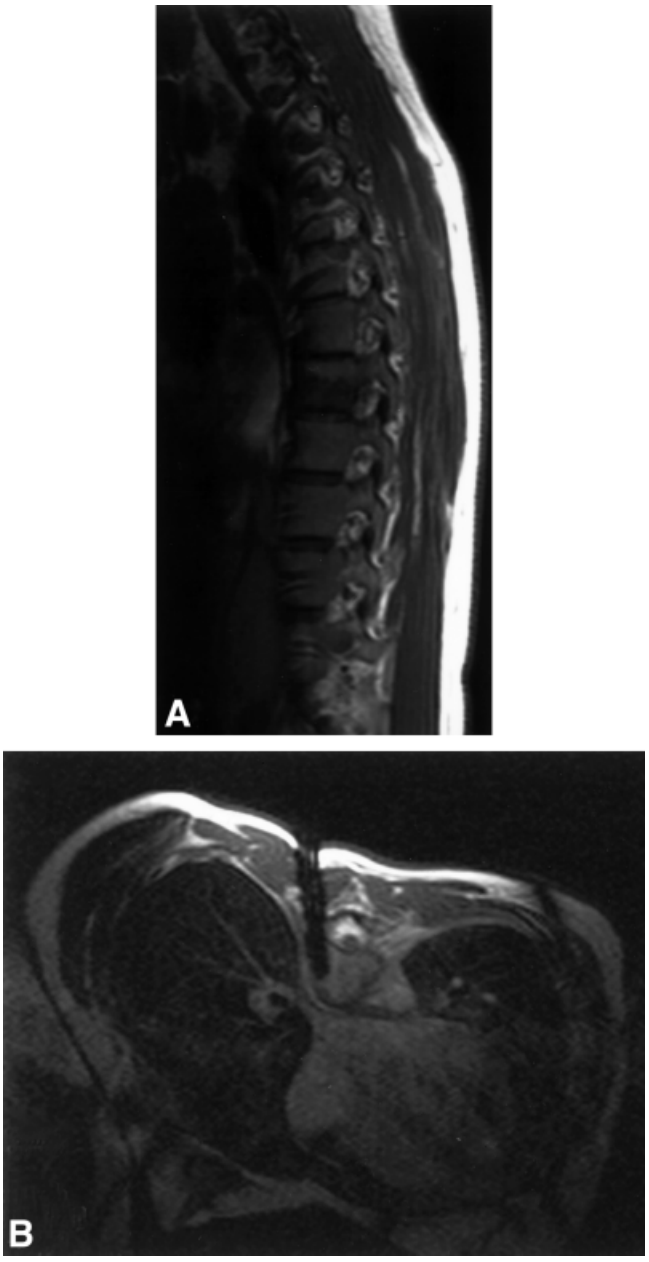


Figure 5. Transpedicular biopsy of the 7th thoracic vertebra. **A:** lesion in sagittal T1 FSE, **B:** needle in the lesion through the pedicle, an axial two-dimensional C-BASS sequence.

tions, as well as in surgical operations (12,13). Direct attachment of the needle to the optical tracking system was beneficial in deep neural drug injections (14). Bending of the needle makes confirmatory imaging more important in fine-needle biopsies and injections than in procedures done with a stiff instrument, such as bone biopsy. In bone biopsy, optical tracking re-

Figure 4. Biopsy of a 9-mm femoral head lesion, axial view. **A:** lesion in pre-operative T1 FSE, **B:** needle approaching the target in fast T1 gradient-echo, and **C:** needle in the lesion in fast T1 gradient-echo.

duced the need for imaging during the procedure and thus reduced the procedure time. A wireless solution for optical tracking was even more important in procedures where the instruments are heavy and clumsy, as it helped to avoid the extra disturbance to handling the instrument by wires.

Saifuddin et al. (15) found ultrasound (US) an accurate (98.4%) guiding method in surface lesions of bone and aggressive tumors that have spread through the cortex. Of the 144 patients referred to a bone tumor unit, 63 (44%) were considered suitable for US-guided bone biopsy because of the relatively large extraosseous component. However, MR imaging as a guiding method has no limitations as to tumor depth and offers better visualization of the deep structures located below the bony or air-containing structures. In soft tissues, traditional sonographic biopsy techniques are faster and more cost-effective than traditional CT techniques, but CT fluoroscopy offers localization advantages over CT with improved procedure times (7). The MR guidance system described here was a fast method compared to conventional CT, and the new fast image formation sequences made it comparable to CT fluoroscopy.

It is reasonable to expect that open-configuration scanners will offer a viable platform for performing bone biopsies. Their openness has additional advantages, including less restricted patient access and easier use of the navigational devices, such as optical tracking systems. MR imaging's high sensitivity in detecting bone and bone marrow lesions allows good visualization of the pathology without ionizing radiation. Furthermore, when choosing the puncture route, the superior soft tissue contrast and the unique three-dimensional imaging capability are of great benefit.

CONCLUSION

MR-guided bone biopsy with wireless optical tracker elements connected to the biopsy set is a feasible and fast procedure, which does not compromise the usability of the bone biopsy set.

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