Eur. Radiol. 10, 36–45 (2000)

European
Radiology

Review article

Interventional MRI of the breast: lesion localisation and biopsy

S. H. Heywang-Köbrunner, A. Heinig, D. Pickuth, T. Alberich, R. P. Spielmann

Diagnostische Radiologie, Martin-Luther-Universität, Magdeburger Strasse 16, D-06097 Halle, Germany

Abstract. With the growing use of breast MRI an increasing need exists for reliable MR-guided preoperative localisation or even MR-guided needle biopsy. In this article an overview is given of the different approaches and the present state of the art. With closed magnets the following approaches have been made: freehand localisation (similar to CT-guided freehand localisation), and freehand localisation combined with a frameless stereotaxic system operating with support by ultrasound. One localisation device for supine localisation and a thermoplastic mesh for breast stabilisation have been reported. Most investigators have used compression devices to immobilise the breast and prevent shift during needle insertion. Thus far, one immobilisation and aiming device has been designed for open magnets. A small number of experiences exist with interventions on open MR units using a navigation system. Wire localisations are presently a well-established procedure. Magnetic-resonance-guided needle biopsy has been accomplished in closed systems as well as by the use of breast immobilisation devices. However, problems still exist due to severe needle artefacts, tissue shift during the intervention and fast equalisation of contrast enhancement in lesions with surrounding tissue. Therefore, needle biopsy is not recommended for lesions < 10 mm. Magnetic-resonance-guided vacuum biopsy is somewhat more invasive but promises to solve most of these problems.

Key words: MR breast biopsy intervention

Correspondence to: S. H. Heywang-Köbrunner

Categorical Course ECR 2000

Introduction

Contrast-enhanced breast MRI has proved to be a useful additional tool for the solution of selected problems. Well-accepted indications meanwhile include preoperative staging before breast-conserving therapy in patients with difficult-to-assess breast tissue, complimentary evaluation of diagnostically difficult breast tissue after breast conserving therapy or silicon implant or search for primary tumour. Furthermore, its use in women at genetic risk is presently under investigation. The major advantage of contrast-enhanced MRI concerns the fact that it has proven able to detect small lesions not yet visible by other modalities in a relevant number of cases; the latter depends on the indication and ranges from 10–39 % [1].

This advantage of MRI, however, turns out to simultaneously be a drawback, unless the question of MR-guided preoperative localisation or MR-guided percutaneous biopsy can be solved for the users of breast MRI and their referring physicians. Exact preoperative needle or wire localisation is important, since small MR-detected lesions are usually nonpalpable and thus difficult to find for the surgeon during operation and for the pathologist. Since enhancement cannot be reproduced on specimens, a reliable countercheck by specimen MR is not possible [2].

According to our own and other investigators' experience the rate of benign to malignant biopsies among MR-detected lesions ranges between 1:1 to approximately 3:1 depending on the diagnostic criteria and the desired sensitivity [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. These results are comparable to the results of conventional imaging without use of percutaneous biopsy.

Since MRI is applied in addition to conventional imaging, however, reduction of open biopsies on MR-detected benign lesions is desirable. Furthermore, a definitive preoperative histologically confirmed diagnosis of malignancy would, particularly in case of MR-detected second foci, be important for planning of the surgical access.

In this article an overview is given about the present state of MR-guided preoperative localisation and percutaneous biopsy.

Materials, methods and results

Localisation procedures for preoperative marking, percutaneous biopsy and other interventions with closed magnets

Closed magnets are by far the most widely used type of MR units. For reasons of image quality they are the only magnets thus far accepted for diagnostic breast MRI.

On these magnets localisation procedures for preoperative marking or percutaneous biopsy have been performed using the following:

1. MR-guided freehand localisation [3, 4, 5, 6], which is similar to freehand localisation under CT guidance [3, 7]
2. Stereotaxic localisation in supine patient position by means of a surface coil with an integrated perforated plate [2, 8]
3. Prone localisation of the compressed breast through perforated compression plates, through compression plates with a window or through compression plates that consist of flexible ribs [9, 10, 11, 12]

Freehand localisation (for preoperative marking or percutaneous biopsy)

Freehand localisation of enhancing breast lesions is performed similarly to freehand localisation of enhancing lesions under CT guidance [3], i. e. the breast is imaged before and after the application of intravenous contrast agent. A skin marker – optimally a tube filled with a solution of MR contrast agent that is attached to the breast parallel to the body axis – is needed to plan the access. Furthermore, a reference transverse slice should be marked, for example, by a vitamin-E capsule. The transverse slice containing the lesion is a slice that is *x* millimetres above or below the slice containing the vitamin-E capsule. This is necessary, since no other fixed coordinates exist within the MR systems that are identical on the MR image and on the patient's body.

The marker tube is visible as a dot on the skin on all transverse slices.

Based on the transverse slice of the lesion the point and angle of needle entry is chosen so that the needle hits the lesion and so that its path is as parallel to the chest wall as possible. This serves to avoid potential injury to the chest wall which might occur while penetrating very rigid tissue.

Freehand localisation has thus far been performed with the body coil or, better, with a surface coil attached to the breast [3, 4, 5, 6, 7].

Advantages of this approach compared with CT-guided biopsy of enhancing lesion include:

1. Exclusion of any error due to pathophysiological differences between enhancement on MR vs CT
2. Use of the more intense signal changes of MR-contrast agent vs CT contrast agent
3. Lower risk of side effects (allergy or potential side effects due to hyperthyroidism or impaired renal function)
4. No associated radiation dose (which includes the contralateral breast and is at least ten times higher than that of mammography)

Disadvantages of MR-guided freehand localisation concern:

1. Long examination time exceeding CT examination time by at least 50 % according to our experience. Here it should be remembered that later than 5–15 min after injection lesion visibility deteriorates significantly due to wash-out of contrast medium from the lesion and due to slowly increasing uptake by surrounding tissues.
2. Increased artefacts on all MR images (3D or 2D) that are not acquired during one breathhold. On spiral CT, in contrast, the complete breast can be imaged during one breathhold with the required resolution and slice thickness. Two-dimensional breathhold MR sequences may be useful during the intervention. For the overview pre- and postcontrast series, however, these sequences have limitations concerning in-plane resolution, slice thickness or number of slices acquired. If small lesions need to be imaged, partial volume and respiratory misregistration pose a problem with the latter sequences.

Thus far, several authors have used freehand localisation for preoperative marking. Based on the published experience of approximately 100 patients MR-guided freehand preoperative needle localisation can be considered feasible, i. e. wire placement within 10 mm of the target is considered feasible after one to several corrective manipulations [4, 5, 6]. Our own experience with MR-guided freehand localisation is limited to approximately 25 cases. Based on the above-described problems we switched from MR-guided freehand localisation to CT-guided freehand localisation. The CT-guided freehand localisation was performed by us until a breast biopsy coil had become routinely available in 130 lesions [7]. Eighty-five of these procedures were performed for preoperative marking, and in 45 lesions a CT-guided percutaneous breast biopsy was performed. The results of CT-guided percutaneous marking were comparable with those of MR-guided marking: wire placement within 1 cm of the lesion was possible in all cases. Despite correct wire placement, two lesions were not removed at surgery. In 6 of 45 CT-guided percutaneous breast biopsies, however, histological findings did not agree with imaging.

Based on published experiences [2, 3, 4, 5, 6, 7] it can be concluded that CT- or MR-guided freehand preoperative marking is feasible. If no other so-called breast biopsy device is available for preoperative marking, this procedure should be performed, since without any preoperative marking no certainty concerning correct excision of an MR-detected lesion is possible; however, free-

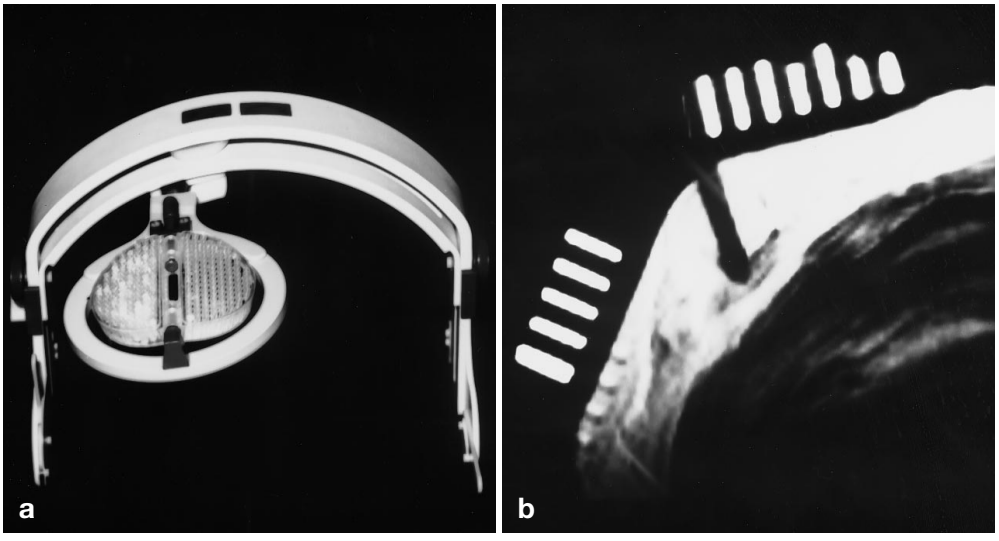

Fig. 1. The biopsy device developed by Fischer and Döler is shown. **a** The device consists of two angulated plates which are surrounded by a surface ring coil. The compression plates contain a Gd-DTPA solution and are perforated by holes which allow needle insertion through the plates. **b** Needle insertion at the lateral margin of the medial plate is shown. The solution within each compression plate is visible as bright signal between the dark straight channels, through which needle insertion is possible. Note the large artefact caused by an MR-compatible needle. (Images provided by U. Fischer)

hand localisation cannot be recommended for percutaneous biopsy.

Stereotaxic localisation in supine patient position

There exists one device which allows stereotaxic supine localisation. Its improved version [2, 8] consists of two angulated plates which are filled with a solution of MR contrast agent and which are perforated by multiple holes that are arranged in columns and lines at regular distances. The holes cross the plates perpendicularly and allow needle insertion through the plate. They are visible on transverse MR images as dark lines that penetrate the thickness of the medial and lateral plate, whereas the solution within the plates that surrounds the holes is imaged with bright signal intensity (Fig. 1).

The two plates are pressed against the breast in question in such a way, that one plate sits on the medial quadrants and the other plate sits on the lateral quadrants of the breast. Thus, shift of breast tissue with relation to the plate is reduced while respiratory motion still occurs. The angulation of the two plates serves to reduce dead space behind the nipple, since needle insertion through the nipple or areola has to be avoided.

The advantages of this system concern low costs and simple application. Disadvantages concern artefacts and blurring due to respiratory motion and the direction of needle insertion towards the chest wall.

Fischer et al. reported use of his device for preoperative marking of 132 MR-detected lesions and for 35 percutaneous needle biopsies [2]. They reported correct wire placement in all 132 lesions, but the surgeon did not succeed in excising 3 of 132 lesions. These patients had to undergo a second surgery. The 35 percutaneous biopsies which they reported consisted of 31 fine-needle aspirations (FNA) with insufficient material in 3 cases and 4 core biopsies. They, however, do not recommend any histological work-up of lesions < 5 mm, surgical biopsy after wire localisation only for highly suspicious lesions of larger than 5 mm and percutaneous biopsy only for lesions > 10 mm.

The device is not commercially available but may be rebuilt, since it is not patented (U. Fischer, pers. commun.)

Localisation of the fixed breast in prone or lateral decubitus patient position

Magnetic-resonance-guided localisation in the prone position has the advantage of reduced respiratory motion. Breast fixation has been attempted by using a mesh that serves as an exoskeleton or by using breast compression between two plates.

First use of a thermoplastic mesh was described by de Souza et al. [13]. Such a mesh is rendered deformable by heating in a water bath of 70–80 °. According to de Souza et al. the mesh is stretched and then moulded around the breast. After hardening it serves as an exoskeleton around the breast. The mesh is then attached both to the patient's chest wall and to a localisation device. The localisation procedures by de Souza et al. [13] were performed in the lateral decubitus position. A receiver coil was positioned underneath the breast and the needle was guided using an ultrasound-based frameless stereotaxic system (Viewpoint, Picker International, Ohio). For the localisation fiducial markers, which are visualised by ultrasound and MR, are attached to the breast. A computer, which is fed with the lesion's MR coordinates with respect to the fiducial markers and which analyses needle position by ultrasound signals obtained from the handle of the needle, is able to calculate the anticipated position of the needle tip within the breast, presuming that no tissue shift or motion occurs during the procedure.

A thermoplastic mesh was also used by Daniel et al. [14] who described 14 freehand localisation procedures, which they performed with a closed magnet (Fig. 2).

Fig. 2. Use of a thermoplastic mesh for MR-guided freehand localisation of a breast lesion on an open 0.5-T MR unit. (From [14]), [Coil: MRI-devices, Waukesha, Wisconsin, USA]

In the publication by de Souza et al. [13] MR-guided localisation was performed in order to obtain FNA cytology. Technically correct needle placement within 2 mm from the lesion at first pass was reported in 8 of 9 patients. Material was inadequate in 2 of 8 cases. The publication by Daniel et al. [14] reports on 14 preoperative localisation procedures for which a thermoplastic mesh was used to support freehand localisation in the prone position. With this technique localisation within 9 mm from the target was reported using up to three manipulations for correction.

Another localisation device, which allows to hit a target through perforations of a guidance plate has been suggested for localisation of breast lesions in 1993 by Hussman [15]. However, with this device the problem of breast fixation was not yet solved, and thus far no further development or clinical application of the device has been reported.

Magnetic-resonance-guided localisation of breast lesions in the prone or lateral decubitus position using perforated compression plates with needle insertion through the compression plates was patented by Heywang-Köbrunner in 1992. It is based on the following principle (Fig. 3):

The patient usually lies prone on the compression device and the breast is compressed between two compression plates. This position is maintained throughout the procedure.

First the lesion is imaged before and after contrast agent. If mediolateral compression is used, transverse images would be best suited to plan the access to the lesion. Markers that are attached to the outside of the compression plate serve to plan the access to the lesion based on the transverse images.

Prone localisation of the compressed breast has the following advantages:

1. Good elimination of artefacts or blurring due to decreased respiratory motion in the prone position and breast compression between two plates
2. Improved fixation of the breast tissue during needle insertion, which may be essential particularly within dense breast tissue

A principal disadvantage of MR localisation during breast compression concerns the fact that strong compression may impair lesion enhancement. This disadvantage has been observed by several groups and has been analysed in a separate study by Kuhl in 1997 [16]. This disadvantage can, however, be circumvented if moderate compression is used. If a lesion enhanced on a previous MRI but not during a localisation procedure under compression, we meanwhile routinely re-image the breast after decompression and re-injection of another bolus of contrast agent. That way absence of enhancement due to too strong (i.e. not moderate) compression (which we observed twice in over 150 patients) can definitely be distinguished from enhancement that varies with hormonal changes.

The first prototype coil by Heywang-Köbrunner based on the aforementioned patent was a device for prone biopsy [9]. A biopsy device for biopsy in the lateral decubitus position was not pursued by Heywang-Köbrunner because of anticipated space problems in the magnet for larger patients. Heywang-Köbrunner's first

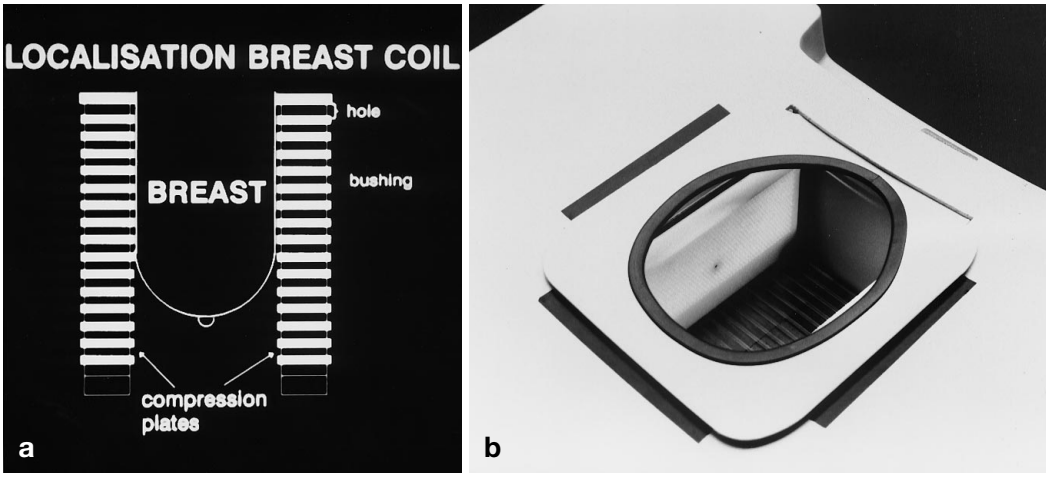

Fig. 3. **a** The concept of the first breast localisation device by Heywang-Köbrunner is demonstrated. **b** The localisation device is shown. In the bottom of the device several tubes with Gd-DTPA solution are contained. Both compression plates are perforated by numerous closely packed holes, which accept bushings for needle sizes up to 16 G

biopsy coil allowed horizontal access to the compressed breast from medially or laterally through the plastic compression plates that were perforated with multiple horizontal holes. For reasons of sterility the holes were large enough to accept a sterile tube-like bushing through which needles up to 16-G could be inserted into the breast, and which guided the needle in a direction that is exactly rectangular to the compression plate.

Two other similar kinds of equipment, one of which also uses perforated compression plates with bushings [10], have been built and tested. The other equipment allows horizontal needle guidance through a fenestrated compression plate by use of an aiming device [11].

Compared to the systems by Heywang-Köbrunner [9, 12] and Orel [11], the system used by Kuhl [10] allows compression of the breast in the mediolateral or craniocaudal direction. Furthermore the patient lies in slightly tilted oblique prone position. This position avoids conflicts with the edge of the curved patient table in case of a strictly horizontal needle path, but reduces the space within the bore.

The systems by Kuhl and Orel [10, 11] only allow a lateral approach to the breast, while the initial (see above) and the new system (see below) by Heywang-Köbrunner allow a lateral and a medial approach to the breast.

General disadvantages of systems using perforated compression plates include the fact that small lesions may be exactly in the area that is inaccessible between the holes. This problem of accuracy due to spacing of the holes is generally minor, if preoperative needle localisation of MR-detected lesions is performed. It may, however, be decisive, if percutaneous needle biopsy of a small lesion is attempted (see below). Another problem concerns aspects of sterility of perforated plates.

Based on the known disadvantages a new prototype localisation and biopsy coil has been built by Heywang-Köbrunner with the support of Siemens Erlangen and Epoxonic. The new coil allows mediolateral compression of the breast by two independently movable compression plates. It allows medial or lateral access to the breast. Different needle angulations are possible. They allow to circumvent the above mentioned problems which concern interference of the edge of the curved patient table with a horizontal needle approach to lesions close to the nipple. Furthermore the angulated approach allows needle insertion parallel to the chest wall, which excludes the danger of chest wall injury. Since the compression plates consist of flexible ribs, which can be spread apart, there is no dead space between the holes. Access through the plates is possible with any needle size or other equipment (Fig. 4 a, b).

Thus far, good experiences have been reported for MR-guided preoperative wire placements performed on localisation devices that allow breast compression. The experiences are meanwhile based on over 200 procedures on MR-detected lesions of any size [9, 10, 11,12]. However, experience with MR-guided biopsies using FNA or core biopsy has even with these devices remained quite limited. That is, the experiences reported by different investigators do not exceed 30 cases [9, 10, 11,17] and most investigators agree that even with devices that allow good immobilisation by means of compression- percutaneous needle biopsy of small lesions (< 1 cm) is a difficult procedure that cannot generally be recommended.

With the new device developed by Heywang-Köbrunner (Siemens, Erlangen, Germany; Epoxonic, Munich, Germany) MR-guided vacuum biopsy has become possible under MR-guidance (Fig. 4c–f) [12]. In contrast to conventional core biopsy, tissue is suctioned into the needle through an acquisition window at the side of the needle. This tissue core is then cut off within the needle by a rotating knife and transported to the back end of the needle, where it is picked off by a forceps while the needle continuously stays in the lesion [18]. By repeating this process and turning the needle around its axis multiple tissue cores are acquired and an area of tissue measuring up to $15 \times 15 \times 20$ mm is removed from inside. That way tissue shift as well as errors of a few millimetres are well compensated for. Furthermore, sampling error can almost be excluded. The fact that the cavity is generally well visible on the post-biopsy images, where partial or complete absence of enhancement may be documented by another pre- and postcontrast series, allows verification of correct sampling, which is another important advantage.

Our present experiences comprise MR-guided vacuum biopsies on more than 120 lesions with a mean size of 8.5 mm. Successful biopsy has so far been possible in all cases except one, where a technical problem with suction occurred. Follow-up of 6–24 months has so far confirmed the diagnoses. The device is presently tested by other investigators, as well, and it is further optimised in a EC multicentre trial (Biomed 2 program).

Localisation and intervention on open magnets

Open magnets are not as widely distributed as closed magnets. They are not used for diagnostic breast imaging for reasons of image quality.

Despite image-quality problems on all open magnets, their use for localisation and interventions appears to be of interest, since they allow direct access to the breast during imaging and thus promise improved monitoring capabilities during puncture or intervention.

Based on the two different open MR systems, on which breast interventions have been performed, different approaches have been described.

The 0.5-T magnet, which presently is by far the most expensive clinical MR system, is equipped with a navigation tracker system. Based on infrared receivers in the MR room angulation of the needle is continuously monitored and imaging in the plane of needle insertion is automatically updated every 4 s. This system has thus far been used for preoperative needle localisation in 5 patients [14] and for monitoring surgery of known benign palpable lesions [19]. Whether image quality would be sufficient for intervention on small lesions and whether small lesions can be hit by a freehand method

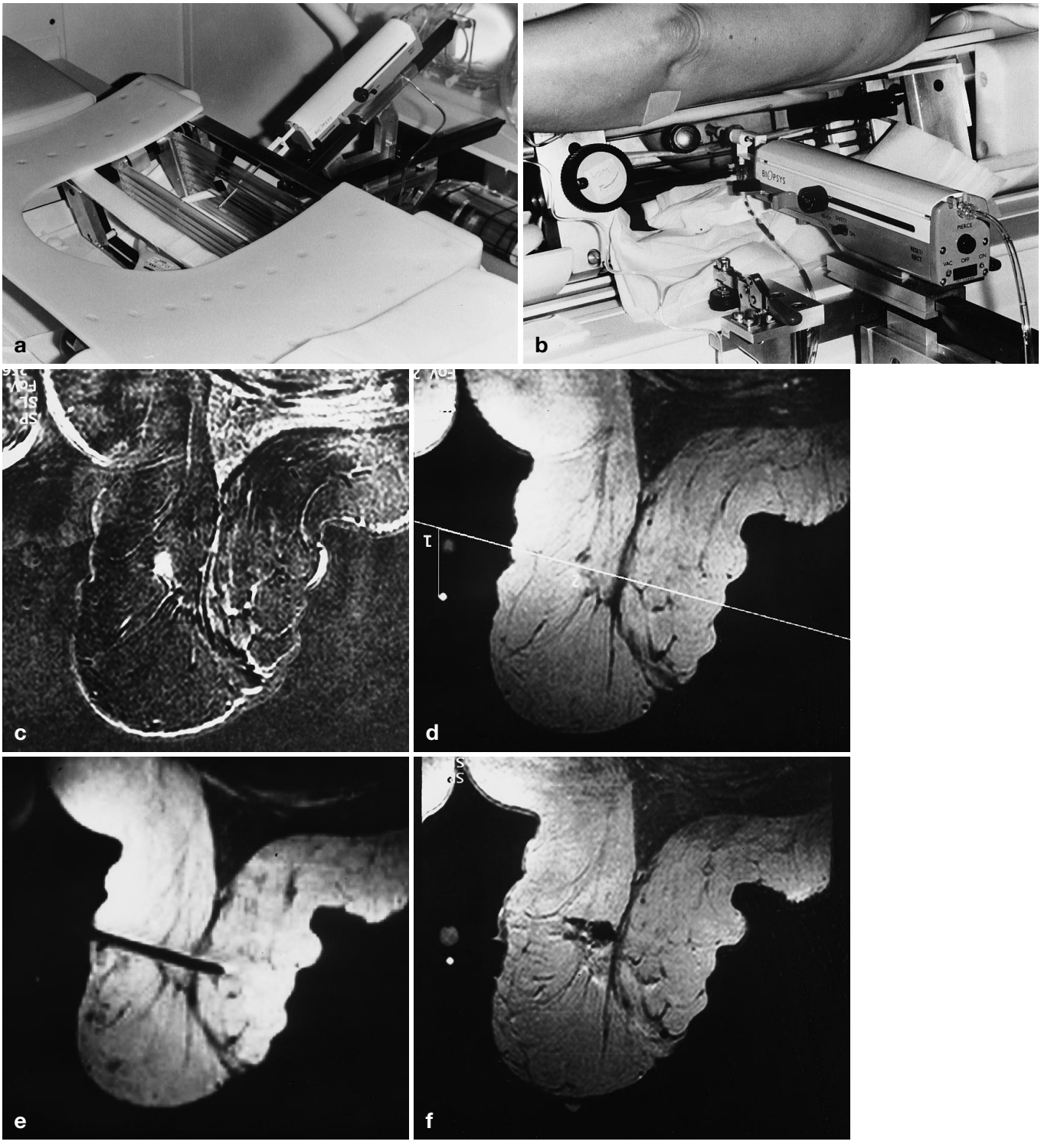

Fig. 4. **a** The new breast biopsy device by Heywang-Köbrunner (Siemens, Erlangen) is shown. It consists of a compression device, into which a ringcoil *(R)* is inserted, and an aiming device, which supports needles, biopsy guns and other interventional devices, and which can be set at variable angulations. **b** An MR-guided vacuum biopsy procedure is shown. In this case the vacuum needle was inserted into the breast through a prototype hard-plastic tube *(T)* which had been inserted by means of a sharp mandril. Since the hard-plastic tube is nonmetallic, it does not cause an artefact. **c–f** Magnetic-resonance-guided vacuum biopsy of an enhancing breast lesion. Histology revealed DCIS with microinvasion. **d** Subtraction image (postcontrast minus precontrast) of the compressed breast before vacuum biopsy. **e** Planning of the access on the postcontrast image before vacuum biopsy. **f** Correct position of the substitute needle (which was used instead of a coaxial system in this patient). **g** Postcontrast image obtained after a second bolus of Gd-DTPA after vacuum biopsy: the major part of the lesion is removed. The cavity is well seen

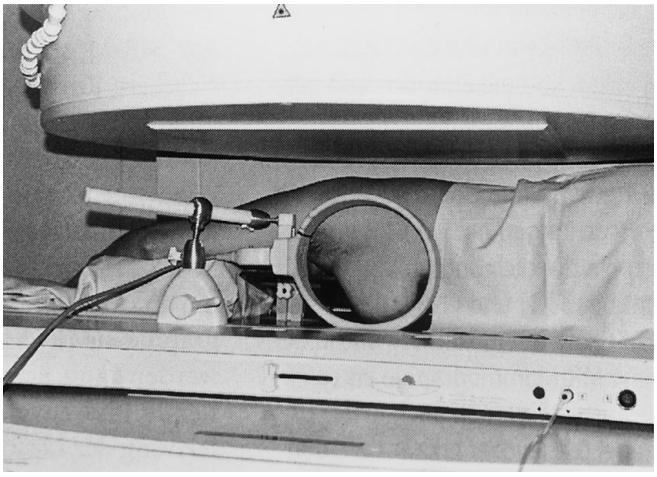

Fig. 5. The localisation device developed by Sittek et al. [21] for use in an open 0.2-T magnet is shown. The large ring contains a surface coil

during the short time period of visible enhancement cannot yet be assessed.

The 0.2-T magnet is by far less costly than the 0.5-T open magnet. Since a navigation system is presently being developed but has not yet been used clinically, almost real-time monitoring of needle insertion is only possible if the needle follows a predetermined imaging plane, which in case of prone breast intervention would in most cases be the transverse imaging plane.

For this MR unit a breast localisation device has been presented by Sittek et al. [20]. It allows breast intervention in the slightly oblique prone position. During the intervention the breast is moderately fixed from medially by the edge of the oblique patient support and from laterally by a ring, which is attached to the patient table and which contains a surface coil (Fig. 5). In order to achieve an image quality comparable to that of high-field systems (where Sittek et al. used a dosage of 0.1 mmol Gd-DTPA/kg), a triple dosage of MR contrast agent (0.3 mmol Gd-DTPA/kg) was applied. Latest results reported by Sittek et al. [21] include 32 successful preoperative marking procedures (accuracy 5 mm) and six percutaneous needle biopsies using 16-G TruCut biopsy needles.

Other breast interventions, for which, however, temperature monitoring may be more important than exact localisation of small lesions, concern MR-guided laser therapies [22]. They have thus far been successfully performed on the aforementioned 0.2-T system using free-hand localisation.

Pulse sequences for MR-guided breast interventions

In principle, the following purposes need to be fulfilled for breast interventions:

1. For lesion detection and localisation, which is necessary to plan the approach, a complete overview of the breast tissue before and after contrast agent in the biopsy position is needed. High resolution and thin slices are furthermore needed for accurate measurements. Very high resolution, however, leads to decreased contrast. Therefore, we meanwhile recommend use of a pixel size of 1–1.5 mm and a slice thickness of 2–3 mm, which may be combined with a dosage of 0.1–0.15 mmol Gd-DTPA/kg. These requirements are usually best fulfilled if 3D gradient-echo sequences with and without image subtraction or with fat saturation are used.
2. For checking needle position fast imaging of a reduced number of slices is sufficient. Choice of a pulse sequence that images the needle or biopsy instrument with the least possible amount of artefacts is important. For this reason we recommend T1-weighted SE or TSE sequences, which image five to seven slices around the lesion.

Available localisation and biopsy materials

Materials for preoperative localisation

Initially, a solution consisting of 1–1.5 ml sterile charcoal suspension 4% mixed with 0.1 ml Gd-DTPA 0.5 mmol/ml and 0.1 ml methylene-blue was used [3]. Although this was the cheapest way, it was not further pursued, since charcoal tends to occlude needles and since exact distribution of any solution within breast tissue is difficult to predict.

Meanwhile wires have replaced marking solutions for most imaging-guided preoperative localisation procedures of the breast and various MR-compatible wires of different shapes are available from different vendors [2]. Since the wires are very thin, artefacts caused by these wires do not generally pose a problem.

Materials for MR-guided percutaneous biopsy

Various types of MR-compatible needles useful for MR-guided FNA are already commercially available. Thus far, only few authors have used MR-guided FNA cytology of breast lesions [2, 13]. In this limited experience thus far correct diagnoses have been reported in 28 of 31 or 6 of 8 lesions. Insufficient material was reported in 3 of 31 or 2 of 8 lesions. Since cytology needles are very thin and have an oblique tip, strong needle deviations may occur in dense breast tissue, which may interfere with sampling of small MR-detected lesions. Furthermore, FNA requires an extremely high level of quality assurance of cytology. Acquisition of insufficient material is a well-known problem of FNA. For these reasons and because MR-guided localisation generally is a very complicated and expensive procedure, where successful sampling should be guaranteed, we have decided against MR-guided cytology.

For MR-guided percutaneous core biopsy MR-compatible biopsy needles at 18, 16 or 14 G are available from different vendors. Even though 14-G needles (measuring 2 mm in diameter) are generally recommended for percutaneous biopsy of breast lesions [23],

mostly smaller sizes have been used for MR-guided percutaneous needle biopsies under MR guidance. Needles for MR-guided core biopsies, however, have two major disadvantages: Firstly, MR-compatible needles are obviously not as sharp as regular steel needles. The second problem concerns the fact that depending on their diameter they cause strong artefacts. Even though it is known that the expression of the artefact does depend on needle orientation, it is mostly not possible to change the approach accordingly, since needle orientation is often predetermined by the limited possibilities of patient positioning and space within the magnet.

The problem of needle artefact is twofold [24]: On the one hand the needle causes a signal void, which, depending on needle orientation and on the nonmagnetic material used, may range between three to nine times the needle diameter. This signal void may completely obscure small lesions and does not allow to exactly predict the needle tip. On the other hand, the distortion of the magnetic field due to the needle leads to a shift of the needle artefact by up to five times the needle diameter.

All of these problems are aggravated by the necessity of using large needle sizes and by the small size of most lesions that are only visible on MRI.

Even though use of a nonmetallic (hard-plastic) coaxial system might solve the problems with artefacts, to our knowledge no such system is presently available on the market. Such a prototype system has been used by us on the first patients who underwent MR-guided vacuum biopsy at our institution (Fig. 4b). Unfortunately, the coaxial system, which consisted of a hard-plastic tube and an MR-compatible mandril that was removed after correct tube insertion, was too expensive. Furthermore, insertion of the hard-plastic tube was more painful than the remaining procedure.

Presently, for MR-guided vacuum biopsy first an MR-compatible substitute needle is inserted which, except for its much thinner diameter, is identical to the Mammotome needle. After correct positioning within the breast has been verified, this substitute needle is replaced by the vacuum needle. This is possible by exchanging this needle against the Mammotome without changing the position of the aiming device. This exchange has thus far allowed to check correct dummy needle position with only small artefacts in the image [25]. Since the thick vacuum needles are exclusively used outside the magnet, they need not be made of MR-compatible material. The latter is advantageous for improved cutting, reasons of costs and availability.

Discussion

Histological work-up of MR-detected breast lesions has become an issue of increasing importance. Exact preoperative localisation or reliable percutaneous biopsy are necessary to both detect small malignant foci that are just MR visible or to histologically verify benignity of enhancing MR-detected lesions.

Preoperative marking of MR-detected lesions is possible by practically any of the methods mentioned herein. Best results and the least number of needle manipulations have been reported for those procedures in which the breast could at least partly be immobilised during puncture [8, 9, 10, 11, 12, 13, 14]. Potential problems of too strong compression are known and can be avoided [16]. The lowest possible number of manipulations is important not only to decrease imaging time and reduce discomfort for the patient. It is also necessary for reliable lesion visualisation, since with increasing time after contrast injection lesion visibility decreases.

Whatever procedure is used, preoperative marking of lesions that are only visible on MRI must be requested. Accuracy should be as good as possible, and wire placement should be no worse than 10 mm of the target. These strict requirements are needed for the following reasons:

1. Since lesions that are visible on MRI alone are generally nonpalpable, they are difficult or even impossible to detect for the surgeon and for the pathologist in situ who needs to select areas for staining within the specimen. Accurate marking thus is an important prerequisite which is necessary to detect the lesion and to limit the tissue volume of diagnostic excision.
2. Since neither specimen MR nor specimen radiography or ultrasound allow verification of lesion excision with a sufficient degree of reliability [2], the best possible accuracy of localisation should be attempted.

Despite exact preoperative localisation, unsuccessful diagnostic excision may occur and has also been experienced after MR-guided wire localisations [2, 7, 10]. These errors are known to occur in 2–5 % of nonpalpable lesions after mammographic wire localisation as well and are probably mostly due to wire displacement before or during surgery. Considering the described difficulties we agree with other authors that if any discrepancy exists between the histological result and the expected lesion based on imaging, a repeat MR must be recommended. The repeat MR should be performed as early after surgery as possible to avoid disturbing enhancement due to granulation tissue [2, 26].

Compared with surgery after preoperative marking for suitable cases, percutaneous biopsy promises the following advantages:

1. Provided a sufficient reliability can be achieved, open biopsy may be avoided for a significant number of benign enhancing lesions. This would concern approximately 75 % of the lesions that are visible only on MRI. Of course, such work-up is only acceptable if a sufficiently reliable and reproducible procedure exists and if in the individual case the histological result is compatible with the imaging findings. Magnetic-resonance-guided percutaneous biopsy could then help to save costs and unnecessary surgery and could enable the radiologist to immediately solve those problems that have been created by imaging. Since surgery after MR-guided wire localisation requires additional organisational efforts and is – due to the lacking usefulness of

specimen MR – still thought to be associated with more uncertainties than other localisation procedures, clinicians are generally willing to support such work-up.
2. Since particularly in case of a suspected secondary focus percutaneous MR-guided biopsy could allow preoperative verification, therapy planning can be improved. Since frozen sections are not considered adequate for nonpalpable lesions, preoperative therapy planning cannot be definitive if a questionable second focus undergoes diagnostic biopsy during surgery of the first lesion.
3. Percutaneous MR-guided biopsy can be performed on an outpatient basis in specialised centres. The biopsy site can be marked by a clip, which allows reexcision in case of malignancy after a usual mammographic or sonographic localisation of the clip. Preoperative MR-guided marking for outside hospitals, in contrast, may be more complicated [27].

Based on the above-described potential advantages of MR-guided percutaneous needle biopsy, various groups have started to investigate the possibilities of MR-guided percutaneous biopsy. Thus far, however, MR-guided FNA or core biopsy have been associated with various problems:

1. With closed magnets the procedure can only be performed outside the magnet. Thus, monitoring of tissue shift during needle insertion is not possible. After needle biopsy only indirect signs (sometimes air may be seen in the site of biopsy, and one investigator left a wire in the area of biopsy) may suggest correct biopsy.
2. The use of compression devices that contain metal parts or biopsy guns which contain metal are not possible on both open and closed magnets.
3. Visualisation of the lesion and assessment of correct needle placement may be severely impaired by the signal void, which is large even with spin-echo sequences and use of nonmagnetic needles with a diameter > 1 mm.
4. Important inaccuracies may be introduced by misregistration of the signal of any needle. Even if nonmagnetic needles are used, the needle artefact may be imaged several millimetres away from the true needle position [24].
5. Finally, nonmagnetic biopsy needles are known to be less sharp than the needles which are available for mammographically or sonographically guided biopsy [13, 17], which may increase problems with insufficient material.

The aforementioned problems may explain the still limited number of MR-guided biopsies that have been reported and the hesitations of most authors against the use of MR-guided percutaneous biopsy particularly for the work-up of lesions < 1 cm; however, mostly *small* lesions cannot be visualised by other methods.

Magnetic-resonance-guided vacuum biopsy promises to solve many of the aforementioned problems, since inaccuracies due to tissue shift during needle insertion, due to other technical causes as well as sampling error, may be compensated by vacuum suction and excision of a larger volume. Misregistration of the needle artefact is reduced by imaging a thin substitute needle instead of the vacuum biopsy needle [12].

Finally, correct biopsy can be directly checked by visualisation of both the cavity and absence of enhancement after a second injection of MR contrast agent. Our present experiences confirm these advantages and show that small size is no limiting factor for vacuum biopsy. Of course, this method needs to be checked by other investigators, as well. Checking, investigation of its use and further optimisation is presently underway.

Thus, in summary, MR-guided preoperative marking has become an important and indispensible procedure that must be provided if breast MRI is performed. Several possibilities exist and care should be taken for an accurate preoperative marking. Magnetic-resonance-guided percutaneous FNA or core-needle breast biopsy presently cannot be recommended for lesions < 1 cm. This procedure still has to be considered as a method under investigation. Presently, MR-guided vacuum biopsy promises to best solve the known problems; however, further experience is needed.

References

1. Heywang-Köbrunner SH, Viehweg P, Heinig A, Kuechler C (1997) Contrast-enhanced MRI of the breast: accuracy, value, controversies, solutions. Eur J Radiol 24: 94–108
2. Fischer U, Kopka L, Grabbe E (1998) Magnetic resonance guided localisation and biopsy of suspicious breast lesions. Top Magn Reson Imaging 9: 44–59
3. Heywang-Köbrunner SH (1990) Contrast-enhanced MRI of the breast, 1st edn. Karger, Basel
4. Brenner R, Shollock F, Rotherman B, Giuliano A (1995) Technical note: Magnetic resonance imaging-guided pre-operative breast localisation using a "free hand technique". Br J Radiol 68: 1095–1098
5. Coulthard A (1996) Magnetic resonance imaging-guided preoperative breast localisation using a free-hand technique. Br J Radiol 69: 482–483
6. Sittek H, Kessler M, Müller-Lisse U et al. (1996) Techniques for preoperative marking of non-palpable lesions of the breast in MR tomography. RoFo 165: 84–87
7. Viehweg P, Heywang-Köbrunner SH, Beck R, Buchmann J (1997) CT-guided localisation of breast lesions detected by contrast-enhanced MRI. In: Proc Eur Congr Radiology, ECR 97, Springer, Berlin Heidelberg New York, p 41
8. Döler W, Fischer U, Metzger I et al. (1996) Stereotaxic add-on device for MR-guided biopsy of breast lesions. Radiology 200: 863–864
9. Heywang-Köbrunner SH, Huynh AT, Viehweg P, Hanke W, Requardt H, Paprosch I (1994) Prototype breast coil for MR-guided needle localisation. J Comput Assist Tomogr 18: 876–881
10. Kuhl C, Elevelt A, Leutner C, Gieseke J, Pakos E, Schild H (1997) Interventional breast MR imaging: clinical use of a stereotactic localisation and biopsy device. Radiology 204: 667–675
11. Orel SG, Schnall MD, Newman RW, Powell CM, Torosian MH, Rosato EF (1994) MR imaging-guided localisation and biopsy of breast lesions: initial experience. Radiology 193: 97–102
12. Heywang-Köbrunner S, Heinig A, Schaumlöffel U, Vieweg P, Buchmann J, Lampe D et al. (in press) MR-guided percutaneous excisional and incisional biopsy (PEIB) of breast lesions. Eur Radiol

13. Souza N de, Coutts G, Puni R, Young I (1996) Magnetic resonance imaging guided breast biopsy using a frameless stereotactic technique. Clin Radiol 51: 425–428
14. Daniel BL, Birdwell RL, Ikeda DM, Jeffrey SS, Black JW, Block WF et al. (1998) Breast localisation: a freehand, interactive MR imaging-guided technique. Radiology 207: 455–463
15. Hussman K, Renslo R, Phillips JJ, Fischer HJ, Khalkhali I, Braslau DL et al. (1993) MR mammographic localisation. Work in progress. Radiology 189: 915–917
16. Kuhl CK, Leutner C, Mielcarek P et al. (1997) Breast compression interferes with lesion enhancement in contrast-enhanced MR imaging. 205 (P):538
17. Kuhl C, Wardelmann E, Leutner C et al. (1999) MR-gesteuerte stereotaktische 14G-Koaxial-Stanzbiopsie zur histologischen Abklärung unklarer, nur MR-tomographisch sichtbarer Herde. RoFo 170:S74
18. Heywang-Köbrunner SH, Schaumlöffel U, Viehweg P, Höfer H, Buchmann J, Lampe D (1997) Minimally invasive stereotactic vacuum core biopsy (VCB). Eur Radiol 8: 377–385
19. Gould SWT, Lamb G, Lomax D et al. (1998) Interventional MR-guided excisional biopsy of breast lesions. J Magn Reson Imaging 8: 26–30
20. Sittek H, Perlet C, Herrmann K et al. (1997) MR-Mammographie: präoperative Markierung nicht-palpabler Mammaläsionen am Magnetom Open bei 0.2 Tesla. Radiologe 37: 685–691
21. Sittek H, Linsmeier E, Perlet C et al. (1999) Markierung und Biopsie nicht-palpabler Mammaläsionen mit einer Zieleinrichtung am Magnetom Open bei 0.2 T. RoFo 170:S72
22. Hall-Craggs M (1997) Breast MRI monitors effect of laser therapy. Diagn Imaging Europe:47–54
23. Liberman L, Dershaw DD, Rosen PP et al. (1994) Stereotaxic 14 gauge breast biopsy. How many core biopsy specimens are needed? Radiology 192: 793–795
24. Ladd ME, Erhart P, Debatin JF, Romanowski BJ, Boesiger P, McKinnon GC (1996) Biopsy needle susceptibility artifacts. Magn Reson Med 36: 646–651
25. Heywang-Köbrunner SH, Kolem H, Heinig A (in press) MR-guided in- and excisional biopsy of enhancing breast lesions using an improved MR biopsy device and a directional vacuum-assisted (DVA) breast biopsy gun (Mammotome). Electromedica
26. Orel SG, Reynolds C, Schnall MD et al. (1997) Breast carcinoma: MR imaging before reexcisional biopsy. Radiology 205: 429–436
27. Warren RML, Hayes C (in press) Localisation of breast lesions shown only on MRI: a review for the UK study of MRI screening for breast cancer. Clin Radiol