An orthesis for reproducible kinematic MR imaging of the shoulder

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Summary

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Background: In general the standard MRI diagnostic of the shoulder in a circumferential high-field, whole body MRI magnet is performed with adducted arm due to the magnet configuration. An alternative arm position is the ABER position. The patient's hand is behind the head. Vertical and horizontal open, whole body MRI magnets allows new possibilities for MR imaging in other joint positions which are representative for diseases of the shoulder joint (e.g. impingement, rotator cuff disease, glenohumeral instability). An essential prerequisite for such investigations is a stable fixation of the arm by use of a MR-compatible device.
Objective: The purpose of this study was the development of an MR-compatible device for the positioning of the shoulder in an open, whole body MRI magnet. The device should be universally usable on men and women and be adaptable onto the different heights. Furthermore defined joint positions should be adjustable and the movements of the shoulder should be quantifiable.
Materials and methods: Materials of aluminum and brass were embedded into glycerol gelatine for the artifact diagnostic. The examination was performed in an open, whole body MRI system with 0.5 Tesla superconducting magnet (Signa SP/i, General Electric, Milwaukee, WI). Different pulse sequences (Spin-Echo, Fast Spin-Echo, Gradient Echo) were used. Only MR-compatible materials of aluminum and brass as well as materials of plastic and textile were used for the construction of the device for shoulder positioning. The correct function and the MR-compatibility were verified.
Results: The device for shoulder positioning consists of three parts: the basis component, the universal component and the right and the left arm component. The device allows movements of the shoulder in all degrees of freedom. The axis of rotation of the device can be adjusted depending on the axis of rotation of the shoulder joint. The quantification of the joint movement is possible by use of a graduation in steps of 15 degrees. By use of the device artifact-free investigations of the shoulder can be peformed in functionally important joint positions (e.g. the apprehension-test position).
Conclusion: The development of a MR-compatible device for shoulder positioning in an open, whole body MR magnet is presented.
Keywords: shoulder, shoulder positioning device, magnetic resonance imaging, open MRI

Introduction

The standard diagnostic of MRI is usually performed in a circumferential, whole body system with high field strength (1 or 1,5 tesla). MR imaging of the shoulder in circumferential, whole body magnets approves only few joint positions. In general the arm is positioned along the body; alternatively the ABER-positioning is used. In the ABER-positioning the patient's hand is behind the head. In circumferential high field, whole body magnets the shoulder movements are limited on a small internal and external rotation. In the contrast to that painful malfunctions may become symptomatic only in other joint positions and during movements. In the neutral position of the arm (arm along to the body, no internal and external rotation) most patients are pain-free. Numerous shoulder disorders cannot be proved in the neutral position (e.g. anterior shoulder instability). Therefore the clinical investigation includes specific clinical tests by which the shoulder joint is examined in different positions and during movements.
The apprehension-test is the best known specific clinical test for the diagnostic of anterior shoulder instability [8]. The patient's shoulder is positioned in 90 degrees of abduction and then maximally externally rotated. In patients with symptomatic anterior instability, the patient will experience apprehension that the shoulder will dislocate.
The examination for impingement and rotator cuff disease also includes specific clinical tests. The active abduction of

the arm between 60 and 120 degrees is painful (painful arc). The impingement sign, described by Neer [6], is pain elicited with maximal passive glenohumeral forward flexion with the shoulder in neutral rotation, which impinges the inflamed supraspinatus and biceps tendon and the subacromial bursa under the anterolateral edge of the acromian.
Open, whole body MR magnets first offer the possibility of the MR imaging of the shoulder in these and other clinically relevant arm positions. Today horizontal and vertical open MR systems are available (Fig. 1). Motion artifacts are a main problem of the MR imaging of the shoulder. A stable storage of the arm is necessary to avoid disturbing movements. Specific storage devices are necessary. The storage device must be free of ferromagnetic materials in order to exclude ferromagnetic artifacts. Pure aluminum and brass are not ferromagnetic materials. On the other hand these components can contain small parts of ferromagnetic substances (iron, nickel, cobalt). A survey of metallic objects (implants, materials, devices, appliances) and MRI under special consideration of the safety for the patient is published by Shellock [9]. MR-systems with open configuration generally may facilitate movement investigations of the shoulder in all planes. However a specific storage and positioning device is necessary. A positioning device for an horizontal open, whole body MR magnet has been described by Graichen [5], for the shoulder investigation at 60°, 90° and 120° of abduction in the scapular plane. Up to now there is not any MR-compatible device for three-dimensional shoulder positioning in the open, whole body MR magnet.
The purpose of the study was the development of a MR-compatible device for three dimensional shoulder positioning for reproducible and artifact-free MR imaging of the shoulder.

Materials and methods

Material tests

Aluminum and brass were used as materials for supporting components and articulated combinations of the device. For the exclusion of ferromagnetic artifacts these components were subjected to an artifact diagnostic. The materials of aluminum and brass were embedded in glycerol gelatin DAB 9 (gelatin 12.5 g, glycerol 62.5 g, sol. sodium. chlorat. 0.9% 25,0 g) (Fig. 1) and examined then in a vertical open, whole body MR system (Signa SP/i 0,5T; General Electric Medical Systems, Milwaukee, WI, USA) (Fig. 2). The pulse sequences were: fast spin-echo pulse sequence (TR=2500 msec, TE=108 msec), spin-echo pulse sequence (TR=440 msec,TE=17 msec), fast multislice spoiled gradient echo sequence (TR=30 msec,TE=7.8 msec). The imaging parameters were: field of view 24 x 24 cm, matrix 256 x 128, Nex 0.5, layer thickness 10.0 mm, space 1.0 mm. A flexible surface coil was used. In the image analysis the occurrence of ferromagnetic artifacts was evaluated qualitatively and quantitatively.
An artifact diagnostic of the plastic and non metal components of the shoulder device was not necessary.

Figure 1. Aluminum and brass material embedded in glycerol gelatine (DAB 9) for artefact diagnostic

Figure 2. Open, whole body MRI magnet (Signa SP/i 0.5 T, General Electric Medical Systems, Milwaukee, WI, USA)

Construction of the device

For the stable positioning of arm and shoulder in an open, whole body MRI magnet a specific diagnostic device was designed. Reproducible three-dimensional examinations of the shoulder should be possible. The shoulder device should be used independently of sex, height, weight and body side. The main features of the device are summarized in Table 1.

For the quantification of the joint movements a graduation of the articulated combinations of the device in steps of 15 degrees was planned. A further emphasis was the adaptation of the rotation axes of the device to the corresponding movement axis of the glenohumeral joint.

- Universally usable, independent of body height, weight and side
- Simple and rapid adaptation to varying body size without the use of new components
- No ferromagnetic artifacts due to the use of MR-compatible materials
- Stable fixation of arm and shoulder to avoid disturbing motion artifacts
- Simple application of the shoulder positioning device
- Adjustment of defined joint positions of the shoulder
- Examination in all motion planes
- Rapid change of three-dimensional position of the shoulder

Table 1 Requirements for a device for shoulder examination in an open, whole body MRI magnet

Results

Material tests

The components of aluminum and brass embedded in glycerol gelatin (tubes, plates, screws) were examined in the open MRI system with different sequences and the occurrence of metal artifacts was analyzed. A considerable artifact by ferromagnetism is shown in Figure 3a, caused by an aluminum disc with iron particles (diameter: 40 mm, thickness: 1 mm). The shoulder imaging is damaged considerably through the ferromagnetic artifact (Fig. 3b). The disc caused a complete signal loss, so that the dorsal parts of the shoulder were not visualized and the adjacent anatomical structures were deformed.

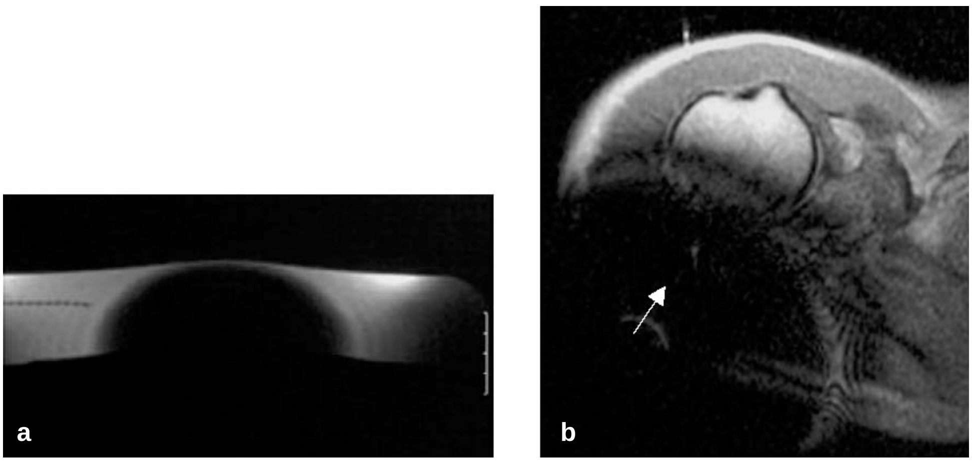

Figure 3. Artifact due to ferromagnetism. a) in Glycerolgelatine embedded aluminum disc with components of ferromagnetic materials (Scale is given in cm), b) axial image of the right shoulder with dorsal loss of the MR signal intensity (arrow) due to the aluminum disc.

Figure 4 shows a typical finding for materials without essential ferromagnetic artifacts. The artifact size almost corresponds to the real size of the examined brass and aluminum components. Further a morphometric analysis was performed in order to carry out a direct comparison between the artifact size and the real size of the examined aluminum and brass components.
Only components which showed no or minimum artifacts were used for the construction of shoulder device.

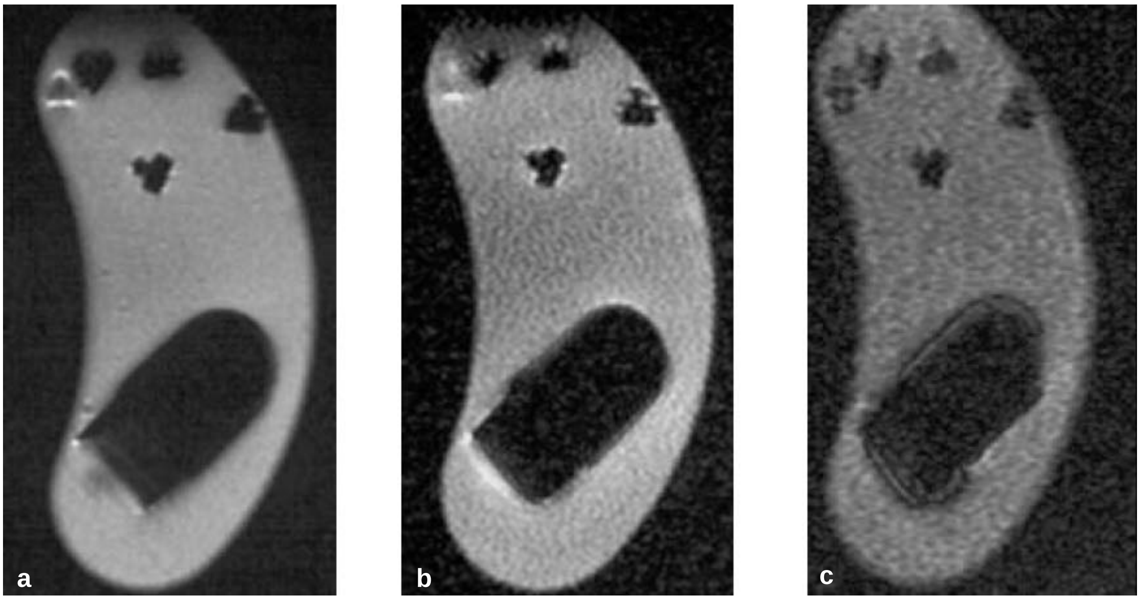

Figure 4. Artifact diagnostic in an vertical open, whole body MRI-system (Signa SP/i, 0.5 T, GE Medical Systems, WI, USA) - in glycerol gelatine embedded material of aluminum and brass. Examinations with varying sequences: a) fast spin-echo pulse sequence, b) spin-echo pulse sequence, c) gradient echo pulse sequence.

Shoulder positioning device

The device consists of three components for an individual adaptation to different body proportions. All used materials of aluminum and brass were subjected first to an artifact
The basic component of the device is a pelvic basket of polyethylene (Fig. 5a). The inner side of the pelvic basket was upholstered with nylon material. According to the proportions of the patient the width of the basket can be adapted individually. In general the adaptation of the width of
The universal component can be attached at the right and left side of the pelvic basket with the aid of two manual screws (fig. 5b). With the aid of the universal component as length adaption is possible according to the height of the patient. The length adaption is with the aid of a glide splint in
The right and left arm component can be simply plugged into the universal component (Fig. 5c). The arm component contains two articulated combinations, one, into height of the glenohumeral joint and the other one in hight of the elbow
The rotation axis in the plane of the glenohumeral joint can
diagnostic. The three components are called "basic component", "universal component" and "right and left arm component".
the pelvic basket occurs in the front part via a strap system with corresponding epoxy buckles. In the reverse page of the pelvic basket the width can be adapted using a specific key. To the right and left side of the basket the universal component can be attached.
the lower part of the universal component and furthermore in the middle part with the aid of a screwdriver possible. The device is fixed with two straps with epoxy buckles at the trunk. The strap system allows an individual adaptation to the proportions of men and women.
joint. The movements can be carried out smoothly and read off in steps of 15 degrees. The two articulated combinations allow a three-dimensional movement of the shoulder. A retainer is used for the fixation of the respective rotation axis.
be adjusted according to the intended movement (abduction

adduction and/or anteversion-retroversion). The articulated combination in hight of the elbow joint faciliates the isolated rotation in the glenohumeral joint. Any joint position can be fixed by a handsrew as described above.
The length of the upper arm and forearm part can be adapted to the corresponding body proportions using an aluminum glide splint. A hand layup can be put individually at both arm parts. The layup surfaces for the arm and the hand were padded out with smooth material.

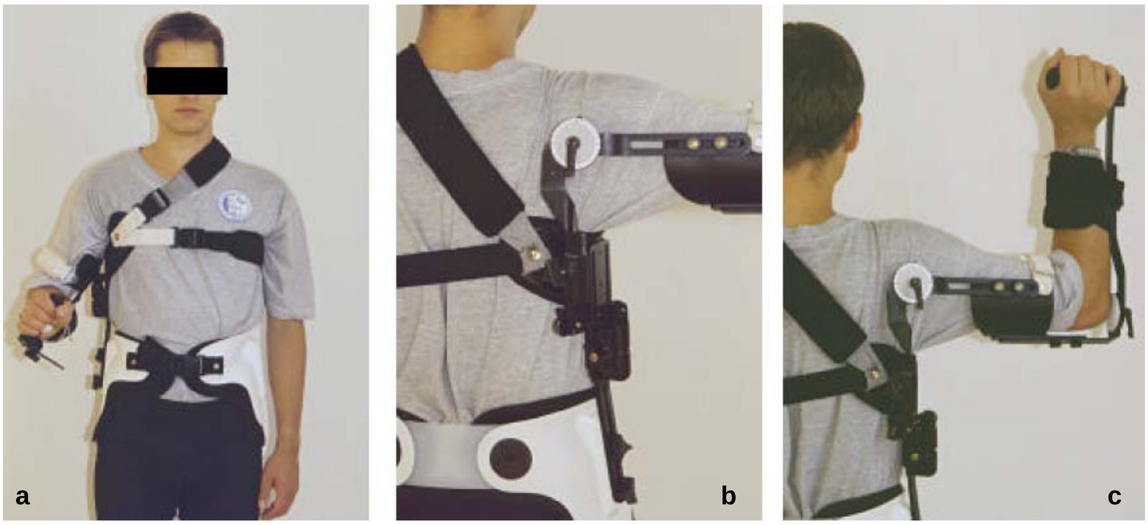

Figure 5. Shoulder positioning device
a) Basic component (arrow) with the possibility of an individual adaptation - in front with strap system and posterior with a specific key,
b) Universal component (arrow) with the possibility to adjust the rotation axis of the device - height adjustment as well as setting in the horizontal plane are done by hand,
c) arm component with two articulated combinations, upper and forearm part as well as handrest - movements can be carried out smoothly and read off in steps of 15 degrees, with the possibility of the individual adaptation of the length of the upper and forearm part as well as individual adaptation of the handrest

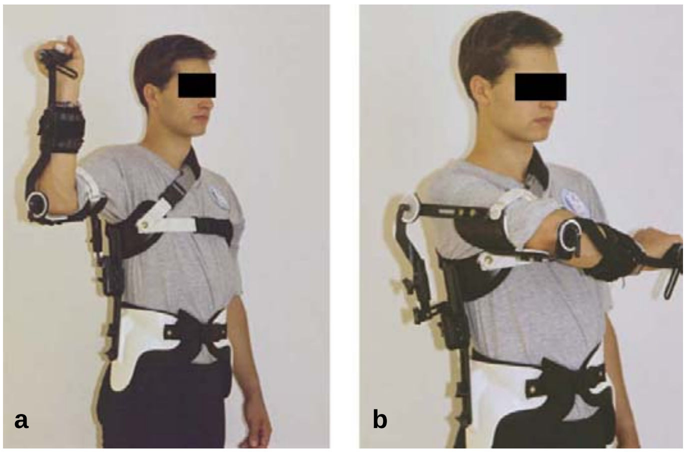

Figure 6. Different joint positions using the shoulder device
a) 90 degree of abduction and 90 degree of external rotation (apprehension-test position),
b) internal rotation of the shoulder in a position of 90 degree of forward flexion (impingement sign described by Hawkins)

In Figure 6 different positions of the shoulder joint using the positioning device are presented. The apprehension-test position which is representative for an anterior shoulder instability is shown in Figure 6a. The impingement-test according to Hawkins is displayed in Figure 6b.

The effectiveness of the positioning device was checked in an open, whole body MRI-system. The device causes no ferromagnetic artifacts in the field of the shoulder. This is exemplary in Figure 7 for a shoulder in the apprehension-test position shown.

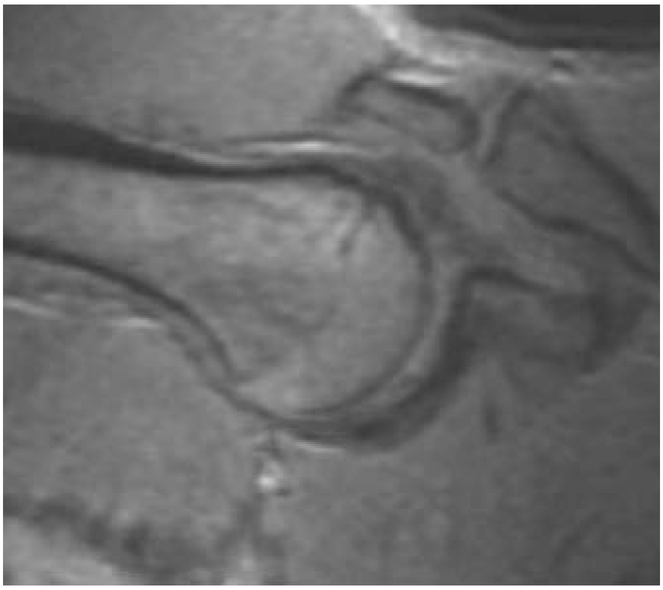

Figure 7. T1-weighted gradient echo image in the oblique coronal plane without ferromagnetic artifacts. The image shows the right shoulder joint of a 31-year old male in the apprehension-test position with aid of the shoulder device

Discussion

The standard diagnostic of MRI is usually performed in a circumferential, whole body system with high field strength (1 or 1,5 tesla). Kinematic investigations of the shoulder are due to the design of the circumferential, whole body systems limited only very much possible. In general the arm is during the MR imaging adducted at the body. Alternative is the ABER positioning described [4]. The new generation of the open, whole body magnets makes kinematic investigations possible in clinically relevant joint positions. Open MR-sytems first also allow MR imaging of shoulder in joint positions which are representative for the different shoulder diseases. An essential requirement for MR imaging with variable joint positions is the stable storage of the arm using a MR-compatible device. A main problem in the MR imaging are motion artifacts [3]. During imaging of the shoulder a sequence requires several minutes. An unwanted movement of the patient influences all images. A stable and comfortable arm storage and a good patient compliance are determinant to avoid motion artifacts.

The new shoulder positioning device as presented in this manuscript has been proved to be MR-compatible. By the use of epoxy, brass and aluminum components no ferromagnetic artifacts have been seen in the examined field of view. Movements in the oblique coronal plane, the scapular plane (abduction/adduction) and in the oblique sagittal plane (anteversion/retroversion) are possible. Thus MR imaging of the shoulder in positions which are relevant for pathological conditions (e.g. apprehension-test position, impingement sign described by Neer and Hawkins) is possible. A stable positioning of the arm during imaging is guaranteed, motion artifacts are reduced to a minimum. Nevertheless joint positions can be adjusted to all movement planes. By the use of scale marks the range of movement can be quantified in steps of 15 degrees. Furthermore a fixation of the connecting segments is possible in every arbitrary rotation position.

With the aid of the MR-compatible device three-dimensional movements can be carried out in the open, whole body MRI system.

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