MRI-Guided Monitoring of Cement Injection in Vertebral Bodies

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Introduction: At last years' ISMRM meeting, we presented modified PMMA bone cement for interventional use in open MRI systems [1] (*fig. 5)*. The scope of the application was to enable MR-monitored kyphoplasty or vertebroplasty. These interventions are used to stabilize osteoporotic fractured vertebral bodies[2], into which bone cement is injected under fluoroscopic guidance[3]. Cement leakage must be avoided in order to prevent complications[4]. In this study, we evaluated various techniques for the save application of cement under MRI - monitoring.

Materials and Methods: All scans were performed in an open MRI system Philips Panorama (Philips Medical Systems; Best; Netherlands), using a sense head coil. Based on an optimized T1 fast spin echo sequence (FSE: TR: 100; TE: 5; FOV: 150x150 mm; α: 110°; voxel: 0,625 x 0,625 x 5mm) with a refresh rate of 2.4s, we tested different techniques to monitor the entire injection volume. Therefore, volume sampling was repeated continuously. The acquired images were displayed on a monitor inside the scanner room. To monitor the cement injection and to prevent leakage, three techniques were evaluated. One method was to scan the volume with parallel image planes (*fig.1*). In the second method, the images planes were arranged in a radial manner centering the injection site (*fig.2)*. The third method was called "zoning" (*fig.3*). In this technique the planes enclosed the perimeters of the filling area. To evaluate the techniques, we monitored a volume in a vertebral phantom (40x25mm) (*fig.4*) while injecting gelatin. The phantom was made up of gel with a cavity at its centre and 3 artificial leakage ducts (3-4mm in diameter) in each direction in space. The filling process of the cavity represented the kyphoplastic procedure. A successful procedure was defined as the filling of the cavity and at least one of the artificial leakage ducts without spillage of filling material. If a filled duct was overlooked and the injected gelatin leaked from the phantom, the procedure was declared to have failed. 10 injection procedures were performed in each of the three monitoring techniques. In a separate experiment, we determined the smallest size of leakage ducts that would be detected with the described T1 FSE sequence by filling 1 to 4mm drillings with the modified PMMA cement in one series and the gelatin mass that was used in the phantom study in another.

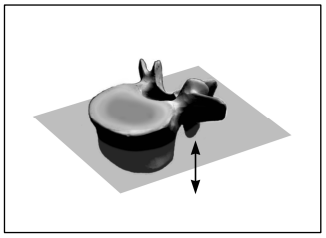

Fig. 1: Continuous "parallel shift" of the plane through the monitored object

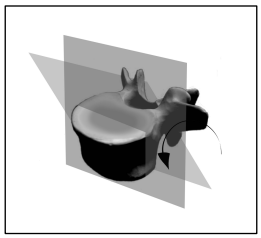

Fig.2: Continuous "radial shift" of the plane around the centre of injection

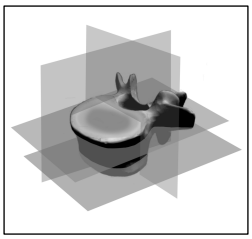

Fig.3: "zoning"- 6 or more static planes are defined to control the filling area

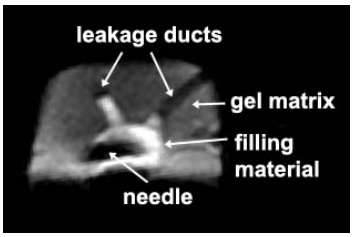

Fig.4: MRI – image of the phantom used for evaluation of the monitoring techniques

Results: The filled leakage ducts with a diameter of 3-4mm were detected in all 30 filling procedures before the filling material leaked out of the phantom, regardless of which scan technique was used. Nevertheless there are differences in scan time and handling. The experimental results of our phantom study are shown in *table 1*. The "parallel shift" technique provided good anatomic orientation and the acquisition of all slices of the vertebral phantom took 18.2s. Leakage detection was sufficient, only leakage ducts vertical to the plane are more difficult to visualize. In the "radial shift" technique the cement was always centered in the image, since the rotation axis was located at the needle tip. The different angulations of the planes provided the best leakage detection, but made anatomic orientation slightly more difficult. For the total volume of a vertebral body approximately 6-8 slices had to be acquired. In one complete turn of the plane the volume was scanned twice. This resulted in a scan time of 43.2s per stack (16 planes). The "zoning" technique saves time by merely scanning the outer edges of the cemented area and thus only took 14,4s. The downside of this fast technique was the imperfect monitoring of the cement injection since the vertebral body was only partially scanned. This technique only enables the surgeon to cease cement injection if and when the cement is detected in the selected peripheral image planes. Therefore, the cement has to be injected more slowly and the interventional time is not as short, as the fast scan technique might suggest. Another detriment is the fact that in most cases leakage ducts are shown in a vertical sectional image, generally complicating the detection of leakage. In our experimental setting the smallest cement filled duct that could be detected had a diameter of 2mm, what represents an area of 3.1mm^3 in a vertical sectional plane.

aspect	parallel shift	radial shift	zoning
scan time (per stack of planes)	18.9 s	21.6s	14.4s
filling time	76 s ± 14 s	85 s ± 41 s	81 ± 16

Table 1

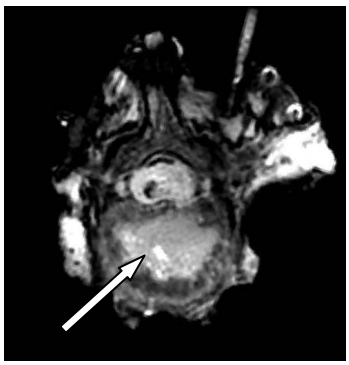

Fig. 5: T1TSE (with SPAIR) human vertebral body filled with an modified PMMA cement (arrow marks the cement in fig. 5)

Conclusion: Monitoring a volume near real-time is still a challenging task. 3D images can be generated, but take a lot of time or do not provide sufficient anatomic information. The experimental results recommend the use of the radial shift technique for monitoring cement injection in vertebral bodies. The scan time may be further optimized, but was already sufficient for the phantom study. The filling time was markedly shorter, than the cement injection time recommended by the manufacturer (*table2*). In a next step, we will further investigate our findings in human vertebral bodies.

BonOs® max. time [min] at 23°C	
Mixing time	0.5
Filling and waiting	4.25
Injection time	6.5
Hardening	8.0

Table 2 : Processing time of PMMA-bone cement „BonOS" – information provided by aap Biomaterials GmbH und Co. KG (Dieburg; Germany)

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